Principles and Tools for Conserving Sites of Geoheritage Significance on the Western Australian Coast

This thesis is presented for the degree of Doctor of Philosophy of Murdoch University
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DECLARATION

I declare that this thesis is my own account of my research and contains, as its content, work which has not previously been submitted for a degree at any tertiary education institution.

Margaret Brocx
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Abstract

The focus of this Thesis is geoheritage of the coastal zone, and thus *coastal geoheritage*. The coast is one of the most complex environments on the Earth’s surface being a zone of intersection and interaction between land, sea, groundwater, and atmosphere. The geodiversity developed along the coast is variable depending on parent rock types, sediments and other materials, local biodiversity, hydrochemical effects, and diagenesis, and variable according to environmental setting and climate. As such, the coastal zone presents complicated products of erosion, sedimentation, biogenesis, and diagenesis, and well-exposed wave-washed, sediment-scoured, and salt-weathered rock sequences. With its complexity and variability, the coastal zone lends itself to developing principles, classifications, and procedures for geoheritage, geoconservation, and policy to protect sites of geoheritage significance.

The coastline of Western Australia is an ideal starting point for the development of a classification of coastal types and for the development of principles for coastal geoheritage because it manifests a wide variety of coastal forms along its 6000 km length and 22° of latitudinal range. It transcends a diverse range of geological regions and several climate zones (from tropical to near-temperate, and humid to arid), encompassing large tracts that are rocky and erosional versus sedimentary and depositional, and fronts various oceanographic and coastal settings (from macrotidal to microtidal, from wave-dominated to tide-dominated to protected, to wind-dominated).

The approach in this Thesis is original in that, for the first time, there is a holistic study that identifies the significance of the coast for its geoheritage values. From forty-four sites described along the Western Australian coast, as well as information from literature review, a new coastal classification was developed, tailored for purposes of comparative geoconservation. Twelve coastal types were identified, categorised as inundational, erosional, depositional, biogenic, and diagenetic types, and their combinations. In addition, a Geoheritage Tool-kit was developed to establish a category-based inventory for identifying and assessing sites of geoheritage significance. The Geoheritage Tool-kit is applied to a selection of four large-scale and four small-scale sites.

Outcomes of this study resulted in the development of concepts, principles, approaches and methods, and classifications with the objectives of identifying, selecting, and assessing coastal sites of geoheritage significance within Western Australia.

Within a National legislative framework in Australia that is biocentric, and a Draft National Heritage Strategy that does not encompass geoheritage, policy specific to Western Australia and the coastal zone was developed in this Thesis. This policy incorporated overall themes and philosophy of geoconservation with principles and criteria adapted from overseas. More specific policy/policies were designed, tailored to site-specific geological regions, local geomorphology, and hazards resulting from oceanographic and biogeographic setting.
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I thank Vic Semeniuk for his confidence in my work, and inspiration in setting me on a path that led to the joy of discovery in interpreting pages of the geoarchive of the Earth along the Western Australian coast. I also thank him for editing the many drafts of the manuscript, and for kindly providing access to his extensive library and large collection of photographs and slides, a large number of which were used in the illustrations. I thank John Bailey for direction and editorial assistance and for the space to follow my path. For assistance in the final stage of proof-reading and the compilation of this Thesis, I would like to acknowledge, with thanks, Penelope Clifford. I would like to thank Craig Miskell for professional drafting of diagrams from the drafts I provided him.

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Chapter 1: Introduction

The advancement of science and technology in the 19th and 20th centuries underpins unprecedented development and exploitation of the natural environment. This has led to the need for environmental management, the establishment of governance, the enactment of environmental laws and policies, and the development of administrative frameworks. For the purpose of laws and policy, the environment has been divided into the biotic, as residing in the biosphere, and the abiotic, also referred to as the geosphere.

Policy related to the biosphere, a term first used in 1875 by the Austrian geologist Eduard Suess (1831–1914) to describe the space on Earth that contains life, i.e., the biotic, has been termed biopolicy. Policy related to the geosphere has been termed geopolicy. The term geosphere, first used in 1875 (for review see Huggett 1995), is used here according to Friedman (1985) as being all geophysical systems, i.e., the abiotic.

Historically, biopolicy and geopolicy have taken very different paths (Caldwell 1990). Biopolicy, which initially was a relatively minor aspect of statecraft, has been growing in significance since the foundation of The International Union for the Protection of Nature in 1956, now known as the IUCN, and the International Conference on the Biosphere, Paris, 1968. The latter, the Intergovernmental Conference of Experts on the Scientific Basis for Rational Use and Conservation of the Resources of the Biosphere, is widely recognized as a turning point in the emergence of an environmental perspective in the community of international organizations (Caldwell 1990). Here it was recognised that with a world population nearing 3 billion people, and taking into account the wide attention given to Rachel Carson’s book *Silent Spring* (Carson 1962), bringing attention to worldwide pollution from DDT and other chemicals, a critical threshold had been reached, and there was an international call for action (Koffler 1969; Batisse 1969; Dubos 1969; Dorst 1969; Darling 1969), i.e., a call for political intervention in matters to do with the global commons. In contrast, geopolicy, even when tacit rather than explicit, can be characterised by national economic and military strategies, policies and legislation.

Taxonomy, classification, and description of plant and animal species, were developed in the 18th and greater part of the 19th centuries by, for example, Linnaeus (1707–78), Lamarck (1744–1829), Darwin (1809–1882), and Wallace (1823–1913). Their work led to wide-ranging conservation initiatives relating to rarity and/or representativeness of biodiversity. In contrast, the pursuit of knowledge in the geological sciences has led to the wholesale loss of non-renewable resources through largely unrestrained resource exploitation and development. As such, in spite of geology and geological processes underpinning all natural systems, the politics that relate to the geosphere and the biosphere have separate and fundamentally different origins and perspectives.

Geoconservation, as a formal international endeavour, began with the passing of a resolution, “Conservation of Geodiversity and Geological Heritage”, at the General Assembly of the IUCN in 2008, i.e., forty years after the IUCN resolution on the biosphere. The 2008 IUCN resolution includes recognition of the need for conserving representative and vulnerable aspects of the geosphere, as a non-renewable resource, and a long-term objective to incorporate the abiotic component of nature into conservation plans and strategies worldwide (Diaz-Martinez & Guillén-Mondéjar 2008; Diaz-Martinez & Erikstad 2012), i.e., land and natural resources policies are fundamentally inseparable, and so should the policies affecting their use.

However, while geoheritage, as a platform for developing international policies in the arena of geological conservation, was formalised by the IUCN in 2008, geoheritage and geoconservation as being concerned with the preservation of Earth Science features (such as natural and artificial exposures of rocks, geological features such as minerals and fossils, landforms, amongst others) actually was formally recognised earlier in legislation in the United Kingdom since 1949 (for review see Brocx 2008). Since the latter part of the 20th century, geoheritage and geoconservation have become significant endeavours in the conservation of important geological features globally (Gray...
2004). Through various non-government international initiatives, largely beginning with the founding of ProGEO in 1990, and the first Symposium on Earth Heritage held in Digne, France in 1991 (Anon 1991a) where the International Declaration of the Rights of the Memory of the Earth was formulated (Martini 1993), there has been world-wide recognition of the variety of sites of geoheritage significance, their different levels of significance, and the need for and establishment of inventory-based assessment of sites of geoheritage significance. Whilst the conservation of natural habitats and of fauna and flora is still the driving force behind the establishment of protected sites, the importance of conserving sites of geoheritage significance for their intrinsic values, science and education, and tourism, has noticeably increased in recent decades. This is due to economic drivers in tourism and a growing recognition that there is more to geoheritage than an appreciation of exceptional landscapes and unusual outcrops, and an increasing awareness and acceptance that rocks, fossils, soils, stratigraphic exposures, and landforms are the product and record of the Earth's history - providing a geoarchive of key evidence relating to the Earth's development.

It is also now recognised that not only is conservation of our geological heritage fundamentally linked to our social wellbeing and the basis for sustainable development and alternative economy, but that geological diversity is an important foundation for biodiversity. As a result of this recognition, globally, geoheritage and geoconservation have become important because it has been recognised that Earth systems have a story to tell, and are linked to the ongoing history of human development, providing the resources for development, and a sense of place, with historical, cultural, aesthetic, and religious values. In addition, Earth systems are the foundation of all ecological processes and part of the heritage of our sciences (Torfason 2001).

Thus, geoheritage and geoconservation, in their current form in terms of their scope and objectives, have gained momentum in recent years as it has come to be recognised that embedded in the materials and the surface of our globe is the story of the Earth and, if destroyed, this archive is lost to current and future generations, with a loss of the core data of the already discovered information and as yet undiscovered information. For this reason, globally, in recent decades, there has been a drive to preserve the heritage of the Earth in intrinsically significant sites of geoheritage (‘intrinsic’ meaning ‘value for its own sake’), to preserve the history of science as embodied in some classic locations that are culturally significant sites of geoheritage, and to preserve significant sites for Science and Education.

The international literature also reveals that geoheritage, focused on geology and geomorphology, is now important for local cultural reasons, natural resource management, land management, research, education, and tourism (Gray 2004; Brocx 2008; Newsome & Dowling 2010). As a result, various international and intra-national bodies have been established for geoconservation, with agreements, conventions, and inter-governmental and non-government (via non government organisations - NGOs) initiatives that relate to the conservation of sites of geoheritage significance at various scales. A major outcome of this international collaboration is that there are now various global to local inventory-based classification systems for identifying and listing sites of geoheritage significance. The international literature characterises geoheritage as primarily relating to sites of mineral or fossil locations, type sections, classic locations that illustrate Earth history and locations where Earth processes are operating today, and locally with particular emphasis on classic sites where some principles of geology were first conceptualised (e.g., the site of Hutton’s unconformity at Siccar Point, or the site of Lapworth’s mylonite in the Moine Thrust). While the pursuit of geoconservation has resulted in the preservation of sites of geoheritage significance for science and education, and an apparent exclusion of such sites from further developments, an additional, unexpected outcome from geoconservation has been the social and economic significance of sites.

In Australia, while there has been a growing recognition of the importance of features of geological heritage significance Australia-wide, there has been no systematic inventory-based geological survey as has been undertaken in the United Kingdom, and elsewhere in the world. Also, recognition of sites of significance in Australia has not always led to their protection. Sanders (2000) commented that the conservation movement is of the view that Australia’s laws in relation to the protection of geological sites are weak and that the Geological Society of Australia should become a proactive advocate
towards the strengthening of laws to protect sites. In Western Australia, for instance, apart from sites that are captured by National Park, National Heritage and World Heritage criteria, and inscribed mainly under Commonwealth powers, the majority of geological sites recommended by Lemmon et al. (1979), Carter (1987) and Semeniuk (1998) remain unprotected.

While globally, and to a limited extent in Australia, there has been identification of sites of geoheritage importance, and development of inventory-based selection of such sites, currently in Australia there is no National Geoheritage Conservation Strategy, formal definitions, nor any framework that addresses the full breadth and scope of what constitutes geoheritage, nor adequate treatment of the matter of scale, both of which are important to identifying sites of significance. Similarly, significance is noted in many works dealing with geoconservation, but to date the various levels of significance, from international to local, have not been adequately addressed or defined. As will be described and discussed later, the level of importance attributed to a given feature of geoheritage significance is related to how frequent or common is the feature within a scale of reference, and/or how important is the feature to a given culture.

This study
This study builds on Brocx (2008) and develops concepts, approaches and methods, and classifications with the objectives of identifying and selecting sites of geoheritage significance within Western Australia. Western Australia has its own geological story to tell. It offers remarkable, unique, and different geological and geomorphological features of global importance – from the Kimberley ria coast, the Shark Bay stromatolites, the Jack Hills zircon crystals, to the mound springs of the Great Sandy Desert, amongst many others. For this reason, Western Australia can offer sites of special significance to the global network of geoconservation.

However, as will be described later, the coast is one of the most complex environments on Earth, being the interface between land, sea, groundwater, and atmosphere, and carries with it a variety of processes and products variable across climate regions and oceanographic provinces. It also has superb outcrops. In this context, this study is a focus on features of geoheritage expressed in the coastal zone, and features of the coastal zone that are of geoheritage significance. While geologists have long recognised the importance of well-preserved outcrops at the coast, the geoheritage values of the full and integrated range of coastal forms, coastal types, and coastal outcrops have not been formally recognised in that the focus has been on the rock sequence, not on the associated products of the coastal setting.

Sites of geological significance, where exposed on the coast such as the Devonian series in south-western Britain, or Siccar Point, Scotland, are significant because they expose intrinsically important geological features, not because they are coastal outcrops. In the United Kingdom, and in Australia, there are geologically important sites that would be of intrinsic geoheritage significance, but their coastal outcrop amplifies their importance because of the excellent nature of the exposure resulting from the coastal occurrence of rocks. Examples include The Seven Sisters exposing Cretaceous Chalk in coastal Sussex (southern England), the Giant’s Causeway exposing columnar basalt in coastal Northern Ireland, Hallett Cove exposing glacial valley-fill deposits in a valley cut into folded Precambrian rock in coastal Southern Australia, and the Twelve Apostles showing coastal landforms cut into soft Tertiary limestone in Victoria, Australia. These are illustrated in Figure 1.1. In addition to the general geology of structure, contacts, stratigraphy, lithology and palaeontology of the examples cited above, these coastal outcrop occurrences, and coastal outcrop occurrences in general, also often carry other features particular to the coastal settings that add to the geoheritage importance of coastal sites: the style of coastal erosion peculiar to the oceanographic and climate setting and lithologies involved, coastal diagenesis that is related to climate, oceanographic, and host rock setting, the effects of coastal diagenesis that influences the style of coastal rocky shore expression, the preservation or otherwise of sea-level history manifest in the rocky shore geomorphology, and the range of macroscopic to microscopic features that are geomorphically manifest differently depending on rock type and tidal level, and climate.
Western Australia spans a wide range of climate and oceanographic settings, and has a diverse range of geological forms expressed at the shore (Figure 1.2). As such, it has inherent diversity of interacting climate, oceanography, and geology that will result in coastal diversity. Effectively, also Western Australia is at the scale of the entire European coast that borders the Mediterranean Sea. Thus it lends itself to developing a blueprint for inventory-based classification and geoconservation of coastal regions developed elsewhere worldwide, i.e., the west coast of Australia is an excellent setting for developing a model for coastal geoconservation. The objectives of this study are to develop principles and tools as a mechanism for conserving sites of geoheritage significance on the Western Australian coast. To achieve this, a geologic/geomorphic classification of the Western Australian coast for site selection is developed as the basis for geoconservation of coastal types, and the mechanisms and policy instruments that have been or are being developed within Australia and internationally are reviewed in order to find a policy-based solution for geoheritage conservation in Western Australia.

Specifically, this study fills a gap in both describing and understanding the values of Western Australia’s extensive coast, i.e., scale, style of geoheritage (e.g., archival, teaching, research, Australia’s evolution) that potentially can be used as a global model or blueprint for delineating, selecting, and conserving coastal types of geoheritage significance.

The approach to be taken in the first part of this Thesis is novel in that, for the first time, there is recognition of the geoheritage significance of the coast holistically, and it involves an approach using various scales of reference to delineate and select sites of geoheritage significance based on an integrated scalar approach.

**Objectives and Structure of this Thesis:**

There are two parts to this Thesis: (1) the description, refining, and application of the Science of Geoheritage to the coast of Western Australia, and (2) using a science-based approach, to develop policies to select, preserve, and manage sites of geoheritage significance for geoconservation along coastal Western Australia.

In detail, the objectives for the first part of this Thesis are to:

1. Define the scope of geology, geoheritage and geoconservation;
2. Formalise scales of reference, levels of significance;
3. Formalise categories of geoheritage sites, and geosites versus geoparks;
4. Outline why coastal geoheritage is special;
5. Outline why Western Australia provides an excellent case study for coastal geoheritage;
6. Classify the Western Australian coast as a basis for selecting sites of geoheritage significance;
7. Describe the Geoheritage Tool-kit as a method of selecting sites of geoheritage significance; and
8. Apply the Geoheritage Tool-kit to selected sites along the coast of Western Australia to identify and assess sites and features of geoheritage significance.

The objectives for the second part of this Thesis are to:

1. Review the theory and philosophy underpinning Policy and Legislation as they relate to environment, geoheritage and geoconservation;
2. Review the history of and existing approaches to geoheritage and geoconservation in Australia;
3. Review the existing approaches to geoheritage and geoconservation in key regions globally;
4. Review the existing approaches to coastal geoheritage and geoconservation globally;
5. Review existing instruments for geoheritage and geoconservation policy in Australia;
6. Review existing instruments for geoheritage/geoconservation in Western Australia; and
7. Design a framework for policy for coastal geoheritage/geoconservation in Western Australia.
Thus this Thesis progresses from definitions, establishing new classifications and methods (tools) for inventory, assessment, and conservation for coastal geoheritage, applying those classifications and methods to eight to areas and, in the sections on policy, progresses from definitions and reviews of existing policies to designing Western-Australian-specific science-based policies for sites of coastal geoheritage significance.

The structure of this Thesis is as follows:

Chapter 1: Introduction
Chapter 2: Scope of Geoheritage, Definitions, and Terms
Chapter 3: Methods
Chapter 4: Why the coastal zone is a special environment - coastal geoheritage encompassing physical, chemical, and biological processes, landforms, and other geological features in the coastal zone
Chapter 5: Western Australian coast as a case study for coastal geoheritage
Chapter 6: A hierarchical approach to classifying coastal types as a basis for identifying sites of geoheritage significance
Chapter 7: The Geoheritage Tool-kit as a method for selecting sites of geoheritage significance
Chapter 8 Application of the Geoheritage Tool-kit to identify inter-related geological features at various scales for designating sites at the scale of a geopark or geosites: case studies from coastal Western Australia
Chapter 9: Policy and Legislation in relationship to Geoheritage and Geoconservation - Principles and Definitions and their relevance to Geology/Geoheritage
Chapter 10: Policy and Legislation in relationship to Geoheritage and Geoconservation-International case studies and reviews
Chapter 11: Policy and Legislation in relationship to Geoheritage and Geoconservation-Australian case studies and reviews
Chapter 12: Policy and Legislation in relationship to Geoheritage and Geoconservation - matters to be considered in the design of a coastal geoheritage policy
Chapter 13: Policy and Legislation in relationship to Geoheritage and Geoconservation- designing the Western Australian coastal geoheritage policy model
Chapter 14: Summary, Discussion and Conclusions

Papers deriving from this Thesis
The papers listed below were published as an outcome of this PhD study. They dealt with scope, scale, and history of Geoheritage, explored the scope of geoheritage with crystals and small scale geological features, described and recognised the coastal zone as an important environment for sites of geoheritage significance, classified the Western Australian coastline as a basis for the recognising the diversity of coasts, developed the Geoheritage Tool-kit to identify and assess sites and regions of geoheritage significance, and applied the Geoheritage Tool-kit to regions in Western Australia, Morocco, and estuaries.


As the various papers listed above were published as an outcome of this PhD study, they are part of this candidature. They have been used as content in expanded form, or in reduced form, for a number of the Chapters. Thus this Thesis is neither a compendium of published papers nor completely new work presented for the first time. Some Chapters are the published papers but modified for the Thesis (with culling and pruning of information from the original much larger paper, and with changes in format, style, and minor wording), while others are completely new work presented for the first time.

The list below makes clear which Chapters were in part or wholly previously published as papers, and which comprise entirely new material.

Chapter 2: mainly derived from Brocx & Semeniuk (2007) but with major expansion of text for sections dealing with ‘The matter of significance’ (100% expansion of Brocx & Semeniuk (2007), ‘Categories of geoheritage significance’ (300% expansion of Brocx & Semeniuk (2007), ‘Scale and categories of sites of geoheritage significance from geosites to geoparks’ (totally new section), and ‘Summary discussion: the scope of geoheritage in terms of categories, diversity of geology, scale, and significance’ (totally new section).

Chapter 3: totally new Chapter.

Chapter 4: mainly derived from Brocx & Semeniuk (2009a), but with some 30% expansion of the text.

Chapter 5: totally new Chapter.

Chapter 6: mainly derived from Brocx & Semeniuk (2010a), but with major 100% expansion of text.

Chapter 7: totally new Chapter.

Chapter 8: the regional scale geopark areas of the Kimberley Coast, King Sound and the Fitzroy River delta, the Leschenault Peninsula and the Leschenault Inlet estuary, and the Walpole-Nornalup Inlet Estuary, mainly derived from Brocx & Semeniuk (2011a, 2011b, Semeniuk & Brocx (2011), and Chapter 18 by Brocx & Semeniuk in Semeniuk et al. (2011), though all have been edited down in size from the original larger papers. The small scale site-specific case studies of Willie Creek, north of Broome, Entrance Point at Broome, Point Leander at Dongara, and Muderup Rocks at south Cottesloe comprise totally new material.

Chapters 9-14 are totally new Chapters.
Chapter 2: Scope of Geoheritage, Definitions, and Terms

The process of assessing and assigning an area or feature for conservation, i.e., why a site should be selected and preserved for purposes of geoheritage, involves a clear purpose and an inventory, scientific assessments, value judgments, and government policies. In the light of there being no such State legislative mechanism or policy framework to identify and assess areas of geoheritage significance in Western Australia, and minimalistic procedures at the Federal level in Australia, it is important to define what constitutes geology, geoheritage and geoconservation, and what scales of reference and levels of significance can be rigorously applied.

This Chapter will define what is encompassed by geoheritage, define some terms such as geology, geoheritage, geoconservation, and geodiversity, as used in this Thesis, outline the use of scale and levels of significance, and establish some broad categories of sites of geoheritage significance.

Capitalisation of terms and words throughout the text is determined by its formal or informal usage. For instance, ‘type’ as a word, meaning generally a category or class, is in lower case while ‘Type’ in the term ‘Coastal Type’ is referring to a formal recognition of a system of classification. In a similar manner, ‘Geology’ (capitalised) refers to the formal Science of Geology whereas ‘geology’ (lower case) is the informal reference to the abiotic array of rocks and their structures in a given area (e.g., the geology of of the Precambrian rocks in the King Leopold Mobile Zone is complex).

The word ‘feature’ is used to refer to an attribute under consideration; thus, a geological feature is a geological attribute. Sedimentary layering, for instance, may be a conspicuous ‘feature’ of a cliff face. The word ‘form’ is used to refer to the morphology and shape of a coastal area and, in essence, a type of coast – hence coastal form is used to refer to the coast without specifically referring to its being a delta, or a dune barrier, or a ria, and so on. The word ‘element’ is used to refer to the component of a system and, in this sense, it is synonymous with ‘component’. The word ‘package’ is used in stratigraphy to refer to a (usually deterministic) sequence of sediments or sedimentary rock, while the term ‘suite’ refers to the set of sediments that comprise a sedimentary environment (e.g., an embayment suite of sediments refers to sediments that are diagnostic of embayments; these however can be composed of several different packages of sedimentary sequences with the suite). The term ‘geoheritage essentials’ is used to refer to the essential components of the geology of a given area that serve to characterise it – for instance, carbonate sediments, stromatolites, and seagrass bank sediment accumulations characterise the Shark Bay area (Logan et al. 1970) and granite and gneiss are characteristic of the Yilgarn Craton (Myers 1997).

The scope of geology as a basis for geoheritage

As geoheritage and geoconservation are concerned with geology, it is worthwhile to explore what constitutes the science of geology and hence, what may be encompassed by the umbrella of geoheritage and geoconservation.

The term geology, often used synonymously with the term Earth Sciences, is a diverse discipline. Examined in detail, geology and its subdisciplines overlap with other disciplines such as chemistry (e.g., crystal chemistry and geochemistry are subdisciplines both of Geology and of Chemistry, and the study of crystal deformation and crystal lattice defects is carried out in Geology, Material Sciences, and in Engineering). All the subdisciplines of geology in this Thesis are considered to be a part of geology sensu stricto where particular subdisciplines are oriented in their endeavour to the study of the Earth, even if the same subdiscipline is shared by another science. This is important, because this Thesis contends that the full scope of what constitutes geology should be within the scope of what could be considered to be of heritage value, and what is considered to be of geoconservation value. This will include all matters studied in Earth Science, from mountain ranges to crystals, and from solid rocks, including ice masses, to hydrological systems and their hydrochemical products such as precipitates and karst.
The scientific discipline of geology involves subsidiary disciplines of igneous geology, metamorphic geology and sedimentary geology, igneous, metamorphic and sedimentary petrology, structural geology, mineralogy, palaeontology, geomorphology, pedology, hydrology and surface processes such as sedimentology (see Glossary of Geology; [Bates & Jackson 1987]). This traverses a wide range of scales: at the global, continental, to regional scales it includes global tectonics, mountain building, and landscape evolution; at smaller scales it includes Earth surface processes such as weathering, erosion and sedimentation, involving ice, water, and wind; and at microscale it includes diagenesis, crystal defects and deformation, amongst others. Chemically, Earth processes and their products involve studies of mineral precipitation, cementation, solution, and alteration at all scales (Wilson 1954).

For example, to illustrate the scope of what is considered to be geology, and hence geoheritage, in their description of geoheritage features of the Swan Coastal Plain in Western Australia, Semeniuk & C A Semeniuk (2001) identify a wide range of geological features that they considered fall under the umbrella of geoheritage; they include igneous, metamorphic and sedimentary rocks, and their relationships at all scales (e.g., craton/basin relationships), mineral locations, fossil locations, pollen locations, type stratigraphic locations, along with type igneous, metamorphic or pedogenic locations, sites of importance in understanding geological processes, sites of importance geomorphologically, sites of importance pedologically, sites of importance sedimentologically/stratigraphically, sites of importance hydrologically, and sites of profound aesthetic geological importance, or of intrinsic geological value.

The science of geology has been split into two distinct streams or schools - those undertaking investigation of causal processes; and those seeking to historically reconstruct the Earth’s development. These two schools were said to be separated by a "great barrier" (Wilson 1954). They have been termed herein the geological processes school and the historical geological school (or geohistorical geological school), separating process-oriented endeavours from product-oriented endeavours(Wilson 1954). Traditionally, each school has looked at different features of the Earth, using different, though at times, overlapping techniques. These two schools of geology persist today, with one continuing to investigate causal processes such as weathering, erosion and sedimentation, and at the micro-scale, studies such as those into the processes of crystal defects and deformation, while the other, the (geo)historical geologists, working at the macro-regional scale to establish the succession of the Earth’s development, studying global tectonics, mountain building and landscape evolution, i.e., the product of Earth processes, and at the small scale, the history and products of diagenesis, weathering, pedogenesis, metamorphism, and crystallisation. The two approaches overlap in that information about processes is foundational to understanding and interpreting geological products.

Clearly, also, the two approaches generate two diverse conceptual categories on which to consider geoheritage. It is contended in this Thesis that both processes and products need to be addressed in geoheritage and geoconservation. For instance, citing two examples where processes may be extant: the environment and medium that allow dune formation to take place, and the environment and medium whereby diagenesis, such a calcite precipitation leading to dune sand cementation, induced by hydrochemical processes takes place, need to be considered in geoconservation. That is, the environment or setting whereby specific physical and chemical processes are operating need to be identified and conserved. Coastal dune environments producing representative highly attenuated parabolic dunes oriented in the dominant wind direction, or fretted parabolic dunes (such as in the Jurien Bay area and Quinns Rocks area, respectively, in southwestern Australia; see Semeniuk et al. 1989) are examples of areas exhibiting dune formation processes. The various Holocene environments of Shark Bay, wherein there is tidal-zone cementation, anaerobic marine phreatic diagenesis, stromatolite cementation, gypsum crystal formation, and skeletal grain dissolution (Logan 1974) are examples of an area illustrating diagenetic processes. Equally, products of these processes (such as the dunes themselves, or specific crystal formation, cementation, or colour mottling, amongst other diagenetic products) also need to be considered in geoconservation. Thus, geoconservation should focus on processes and their products (as represented in the modern environment, and in the rock as present in stratigraphic sequences, mineral and fossils deposits, and metamorphic and structural terranes).
Table 2.1 presents the range of subdisciplines (process and product-oriented) considered to be part of geology, and which should be considered in inventory-based assessments of geoheritage and geoconservation (from Brocx & Semeniuk 2007).

Table 2.1: The range of main subdisciplines and specialised subdisciplines within geology

<table>
<thead>
<tr>
<th>Main subdiscipline</th>
<th>Selected list of associated more specialised subdisciplines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineralogy</td>
<td>crystallography, mineral chemistry, geochemistry</td>
</tr>
<tr>
<td>Igneous geology</td>
<td>petrology, geochemistry, mineralogy, volcanology, geochronology</td>
</tr>
<tr>
<td>Metamorphic geology</td>
<td>Petrology, geochemistry, mineralogy, geochronology</td>
</tr>
<tr>
<td>Sedimentary geology</td>
<td>petrology, geochemistry, mineralogy, stratigraphy, diagenesis, skeletal taphonomy, ichnology, geochronology</td>
</tr>
<tr>
<td>Structural geology</td>
<td>mechanical deformation, geomechanics, crystal deformation, geometric analyses, terrane analyses</td>
</tr>
<tr>
<td>Marine geology</td>
<td>marine geomorphology, stratigraphy, sedimentology, igneous geology, geochronology</td>
</tr>
<tr>
<td>Stratigraphy</td>
<td>sedimentary petrology, mineralogy, geochronology</td>
</tr>
<tr>
<td>Palaeontology</td>
<td>palaeobiology, palaeoecology, evolutionary biology, skeletal petrology, ichnology, taphonomy, mineralogy, geochronology, biostratigraphy</td>
</tr>
<tr>
<td>Sedimentology</td>
<td>stratigraphy, sedimentary petrology, geochemistry, mineralogy, diagenesis, ichnology, skeletal taphonomy, carbonate sedimentology, terrigenous sedimentology, evaporate sedimentology, fluid mechanics</td>
</tr>
<tr>
<td>Glaciology</td>
<td>ice stratigraphy, ice petrology, crystallography, crystal deformation, geochemistry, sedimentology, glacial geomorphology (including periglacial and paraglacial geomorphology)</td>
</tr>
<tr>
<td>Palaeoclimatology</td>
<td>stratigraphy, geochronology, palynology, biostratigraphy</td>
</tr>
<tr>
<td>Pedology</td>
<td>stratigraphy, petrology, geochemistry, mineralogy</td>
</tr>
<tr>
<td>Hydrology</td>
<td>stratigraphy, hydrogeology, hydrodynamics, hydrochemistry, isotope chemistry</td>
</tr>
<tr>
<td>Geomorphology</td>
<td>fluvial geomorphology, aeolian geomorphology, volcanogenic geomorphology, karst geomorphology, coastal geomorphology, marine geomorphology, desert geomorphology, alpine geomorphology</td>
</tr>
<tr>
<td>Surface processes</td>
<td>geomorphic processes, weathering, erosion, transport</td>
</tr>
</tbody>
</table>

Figure 2.1 illustrates a selected range of geological features in coastal and inland Western Australia that spans the scope of geological phenomena, as listed in Table 2.1, that would qualify to be assessed as sites of geoheritage significance (in addition to the foregoing discussion. These images drawn from Brocx & Semeniuk (2007) provide a spectrum of geological features from the landscape to the geological, from the large scale to the small scale, and covering a range of geological features such as dykes, folds, spits, and duricrust. Figure 2.1 also is used in a discussion of levels of significance to be developed later in this Chapter).

Within Figure 2.1, the aerial view of Cape Range, in mid-western coastal Western Australia, viewed to the south, illustrates a large scale geological and geomorphic feature (Figure 2.1A). The Range is a tectonically uplifted ridge of Cainozoic limestone (Hocking et al. 1987), with post-Tertiary consequent streams. The ridge also records a continuous history of uplift during the Quaternary, reflected in terraces cut into the Quaternary limestones (van de Graaff et al. 1976). Yardie Creek, cut into the limestone, and with a sand bar at its mouth, is in the foreground. Ningaloo Reef is evident in the shallow water to the west. The linear dune field in the Great Sandy Desert (Veevers & Wells 1961) illustrates a desert geomorphic feature of aeolian landforms (Figure 2.1B). The recurved spit of accumulated small shells of *Fragum hamelini* (the Hamelin Coquina of Logan et al. 1970) illustrates a coastal geomorphic and stratigraphic feature, where active Holocene sedimentation has resulted in the development of a prograded shell grit beach ridge system (Figure 2.1C). The buttes in the north-
western Pilbara illustrate geomorphic and geologic features (Figure 2.1D), where Mesozoic sedimentary deposits (the resistant capping) rest with unconformity on Precambrian granite, with the contact representing the stratigraphic interface between deposits of the Canning Basin and the Pilbara Craton. The Pinnacles at Cervantes illustrate a geological and geomorphic feature (Figure 2.1E): calcrite impregnated/cemented pipes, normally buried beneath a cover of yellow quartz sand, stand in relief above an aeolian-eroded landscape wherein the yellow sand cover has been removed. The fold in the rocks of the Brockman Iron Formation of the Hamersley Group (Macleod 1966), composed of laminated ironstone and chert, illustrates a geological feature, that is of a fold formed in response to a decollement in a zone of layer-parallel shear (Figure 2.1F). The outcrop of Bunbury Basalt at Bunbury illustrates the exposure of a valley fill of this basalt exhumed by coastal erosion (Figure 2.1G). Normally, in this region, the valley fills of Bunbury Basalt lie buried below the surface (Playford et al. 1976). The outcrop also shows coastal geomorphic features. The folded metamorphic rock of interlayered mafic (dark coloured) and felsic (light coloured) layers occurring in the Irwin Inlet area, southern coast of Western Australia, illustrates isoclinally folded granulite, and is a structural and metamorphic feature (Figure 2.1H).

**The variety of terms now associated with geoheritage and geoconservation**

Historically, not too dissimilar to the definition and use of words used in nature conservation, such as biodiversity, in the 1970s, in the short time since the coining of the term geoheritage in the 1990s there has already been a proliferation of related terms, and confusion associated with new and existing terms. It is useful therefore to trace the origin of the terms, and discuss the meanings ascribed to the terms geoheritage, geoconservation, and geodiversity. Each of the terms are described below as to their first use, etymological understanding of the terms, and the preferred definition of a given term. More detailed discussion of the definitions and history of the terms geoheritage, geoconservation, geodiversity, and other related terms, as used in the literature is provided in Brocx & Semeniuk (2007). A review and discussion of terms in the arena of geoconservation also is provided by Prosser (2002a, 2002b).

**Geoheritage**

The term geoheritage derives in part from the word geology and from the word heritage, the latter meaning something that has been transmitted from the past, or has been handed down by tradition. The term is used internationally, and in Australia, and carries a notion of the heritage of features of a geological nature. It axiomatically conveys the idea that there is something (valuable or otherwise) to inherit from the past and pass on to the future. The term geoheritage evolved from geological heritage (just as the term biodiversity evolved from the term biological diversity). The term “geological heritage” first makes its appearance internationally in the First International Symposium on the Conservation of Our Geological Heritage at Digne, France in 1991 (Anon 1991a). The term geoheritage first makes its appearance in the literature in the Malvern International Conference, the second international conference dealing with geological and landscape conservation, held in the Malvern Hills (UK) in 1993 (Joyce 1994; O’Halloran et al. 1994). Percival (1985) provides an outline of state of the art of geological heritage in New South Wales, Australia, and had used the term ‘geological heritage’ in a report in 1979.

Between 1991 and 2006, a variety of definitions and concepts of geoheritage and related terms appeared in the literature (see Brocx & Semeniuk 2007). Generally, geoheritage is used as a descriptive term associated with the conservation of Earth features, with theoretical concepts and definitions of geoheritage still in their developmental stage (Sharples 1995, 1996, 2002).

Historically, geoheritage as a concept, (though not as a term), can be traced back to the time when knowledge was being gained from the geological discoveries made during the Industrial Revolution (Busby et al. 2001). As noted earlier, when geologists in the United Kingdom such as Lyell, Smith, Murchison, and Sedgwick set in place the foundations for the science of geology, stratigraphy and palaeontology, built on an understanding of geology both in the field, and on site-specific locations (Hallam 1989), many locations assumed significance as scientists identified type locations and classic
sites. This was based on an appreciation of the significance of the Earth’s crust and the landscape as a basis to reconstruct the Earth’s development and the causal processes. These locations were called sites of Earth Heritage, and preserved as sites of special scientific significance. However, it should be made clear that the protection of these sites came much later than the time of Lyell, etc., and only after 1949 in the National Parks and Access to the Countryside Act.


Sharples (1995) expanded the original idea of geoheritage to include the protection of dynamic geological processes and geodiversity, i.e., processes and products, for their inherent or intrinsic values, and argued that where geoconservation is based on aesthetic, scientific or cultural reasons it actually involves making anthropocentric value judgements with the implication that the natural environment exists only for human use. Dixon (1996) similarly rejects the notion that the natural environment exists only for human use, and raises the question of the ethics and of giving moral consideration to the natural environment for the right to exist without justification. In principle I agree with these notions, however, as geoheritage leads to (active or passive) geoconservation, it involves some degree of assessment and value judgement.

Further formalizing the term geoheritage, a journal, Geoheritage, was launched in 2008 by the publishing house, Elsevier.

In this Thesis, the term geoheritage, expanded and modified from Semeniuk (1996a) and Semeniuk & C A Semeniuk (2001), is used in the following manner:

Globally, nationally, state-wide, to local features of geology, such as its igneous, metamorphic, sedimentary, stratigraphic, structural, geochemical, mineralogic, palaeontologic, geomorphic, pedologic, and hydrologic attributes, at all scales, that are intrinsically important sites, or culturally important sites, that offer information or insights into the formation or evolution of the Earth, or into the history of science, or that can be used for research, teaching, or reference.

Using this definition, geoheritage covers natural features that are intrinsically important (such as the Jack Hills zircons, or the Ediacara fauna), and cultural features (such as the historically important site of the description of an unconformity by Hutton; scenically important sites such as The Twelve Apostles along the coast of Victoria; and culturally important sites such as the Devil’s Marbles in the Northern Territory), where the descriptor ‘cultural’ relates to the ideas, customs, and social behaviour of a society such as local Traditional Owners or Indigenous groups, a local community, or a scientific community (see later) and their value of a geological feature. Intrinsically important sites may be globally unique, while culturally important sites may be common globally, but have a human value, acknowledging that some sites have both an historic as well as an intrinsic value. This distinction is important, in that the former may comprise globally unique sites, while the latter may be important only culturally, e.g., unconformities may be common globally, and may be better examples than at Siccar Point where Hutton described them for the first time, but the location at Siccar Point represents an important historic/cultural as well as (an intrinsically) important geologic/scientific site.

Geoconservation

While geoheritage concerns the heritage of features of a geological nature, geoconservation is the action that works towards the preservation of sites of geoheritage significance. The term geoconservation was coined and began its use in the 1990s (Sharples 1995). Semeniuk (1996a), and Semeniuk & C A Semeniuk (2001), consider geoconservation to be the conservation, or preservation of Earth science features for purposes of heritage, science, or education. Other authors use the term in a similar manner. Etymologically, it combines the action of conservation with “geos” (the Earth), implying conservation specifically of features that are geological. Geoconservation involves the
evaluation of geoheritage for the purpose of conservation and land management, leading to the protection of important sites by law.

In the international literature, geoconservation has a broader scope than is dealt with here, involving the conservation of sites of geoheritage significance, but also deals with, and is involved with matters of environmental management, geohazards, sustainability, and natural heritage as it relates to maintaining habitats, biodiversity, and ecosystems in general. In this Thesis, while the broader implications of the notion of geoconservation as used overseas is accepted, there is a focus that geoconservation is concerned mainly with preserving sites of geoheritage significance. The term geoconservation is used in the sense of Semeniuk & C A Semeniuk (2001), i.e., preserving sites of geoheritage significance.

Geodiversity

Following the introduction of the term geoconservation for the preservation of geological features for their intrinsic, ecological and geoheritage value (Sharples 1995), the term geodiversity was coined and at one stage appeared to be replacing the term geoheritage. Further, some authors made geodiversity analogous with biodiversity (Kiernan 1990; Eberhard 1997). Given the relative success of the term biodiversity in galvanising support for conservation of the biosphere, it was anticipated that the term geodiversity would carry some of the enthusiasm for bioconservation into the realm of the geological systems (Eberhard 1997).

In this Thesis the term geodiversity, which etymologically means the diversity of geological features, is used in the following manner (after Semeniuk 1996a):

the natural variety of geological, geomorphological, pedological, hydrological features of a given area, from the purely static features (i.e., products such as shorelines, sandy spits, or limestone pinnacles, or river canyons) at one extreme, to the assemblage of products, and at the other, their formative processes (e.g., active parabolic dunes forming under a given wind regime).

The term geodiversity is applied only to region-specific or site-specific features. It is not used to mean diversity of all things geological, because the term geology is broad enough in scope and scale (as discussed above) to carry that implication.

Nor is the term geodiversity used as a substitute for the term geoheritage. Geodiversity connotes diversity, whereas geoheritage connotes heritage. Geoheritage encapsulates a specific concept, and the “heritage” portion of the word cannot be rationally substituted for by the suffix “diversity”.

In addition, whilst in the field of conservation the terms geoconservation and bioconservation have parallel meanings, geodiversity and biodiversity do not. That is, substituting “geo” for “bio” in the term biodiversity changes the notional meaning and scale of application of the word.

The use of geodiversity as a term meaning the diversity of geology worldwide is a surrogate term for geology itself, and use of the term in this sense should be abandoned in favour of its meaning as reflecting a site-specific feature of geology, and being linked to biodiversity in that local or regional geodiversity underpins biodiversity (Semeniuk 1996a).

Used in the sense of site-specific or region-specific diversity, the geodiversity of a site or region lends itself to measurement, once the scale of the geological components and the size of the area being measured are given. For example, an intensely fault-splintered terrane in a given region may be comprised of a stratigraphically diverse sequence of rocks, a palaeontologically diverse sequence of formations, and a mineralogically diverse suite of metamorphic rocks. The term geodiversity can be applied to this area, at all scales.
However, given that geodiversity (sensu Semeniuk 1996a) can be measured, it would be erroneous to conclude that it carries with it conservation significance in the same way that biodiversity does. Low geological diversity is not more or less important than high geological diversity. For instance, a thick monotonous sequence of black limestone, spanning 10 million years, accumulating to hundreds of metres thickness may exhibit low (geo)diversity, but it has a story to tell about Earth crust evolution, constancy of basin subsidence, and consistency of hydrochemistry and environment. Geologically complex situations, for example, where a variety of rock systems from various tectonic regimes have been juxtaposed together by faulting and then intruded by a granite batholith, resulting in a wide variety of rock types with a plethora of sedimentary, igneous, metamorphic, and metasomatic minerals can result in a system of high geodiversity. This type of system will have internally complex stratigraphic and structural relationships, resulting in complex hydrology and hydrochemistry, and complex landforms and soils, which in turn result in a complex response in the biota (i.e., species and community biodiversity). But while such a site may be a location where there is a concentration of features useful for holistic studies in that many subdisciplines of geology can be applied to the site, and there is a wide variety of materials for teaching and research, and while it is a site where complexity itself can be researched, it is not inherently a more important site than one with less complexity.

For site-specific and region-specific assessments, to emphasise geodiversity as a basis for geoconservation, as one would emphasise biodiversity as a basis for (bio)conservation, would be placing undue emphasis on terranes that had been, for instance, tectonically derived or tectonically and structurally modified. The logical conclusion would be that the only geological systems or terranes that are worthy of geoconservation are those that have been complexly altered/modified diagenetically, metamorphically and tectonically, and the more complex the alteration, the greater the geoconservation significance. This notion is rejected.

Scale in geoheritage and geoconservation

As described above, a coining of new terms and variable use of meaning of the existing terms in geoconservation, globally, and to some extent in Australia, has resulted in the need to define and redefine the breadth and scope of what constitutes geological heritage, in the recognition of sites of geoheritage importance, and in the development of inventory-based selection of sites. The issue of scale, and its importance to geoheritage, however, has not been dealt rigorously with in the literature, though its principle is implicit in some of the wording in various global Conventions and Acts, and in the Australian Government Acts (Australian Heritage Commission 1990; EPBC Heritage Amendment Act 2003). That is, most of the progress in geoheritage and geoconservation has been scale-independent. However, this matter is important to developing ideas of what is encompassed by geoheritage, therefore, the matter of scale in geoheritage needs to be addressed directly.

Scale is important to consider in geoheritage and geoconservation, because features of significance can range in size from that of landscapes and geological terranes to that of a crystal. A review of the literature shows that in many locations of the world, geological sites are important because of crystal-sized phenomena, and crystal fabrics, because it is often at this scale that the story of the Earth unfolds (Brocx & Semeniuk 2010b). For instance, the snowball garnets of Vatterbotten, Sweden (Barker 1998), the orbicular structures of the Thorr Granodiorite of Donegal, Ireland (Pitcher 1993), or the zoned zircons from Jack Hills in Western Australia (Wilde et al. 2001) all tell important stories about the Earth: the rotation of garnets and their spiralling incorporation of surrounding layered matrix under conditions of shear, or the concentric whisker crystal growth under delicate conditions of growth, diffusion and cooling, or the zoned zircons that illustrate that the Earth was already solid 50 million years after its formation, respectively. Each of these locations represents unique and classic examples of Earth history, yet the history is embedded at the crystal scale.
At the next scale in increasing size, important geological phenomena of geoheritage significance are represented by dinosaur footprints (Geological Survey of Western Australia 1975), fossil sites such as the Precambrian Ediacara fossil fauna in South Australia (Glaessner 1966), the Cambrian Burgess Shale fauna in Canada (Gould 1989), Hutton’s classic unconformity (Hutton 1795, cited in Dean 1992), Lapworth’s mylonite (T A Semeniuk 2003), or egg-carton folds in laminated quartzite and marble (Hobbs et al. 1976). Important geological and geomorphological phenomena continue to occur in increasing scale, right up to the scale of mountain ranges and major drainage basins.

In Australia, a large range of geological and geomorphological features of geoheritage significance, and criteria for their selection, are described and discussed by Joyce (1995), Grimes (1995), and Kiernan (1997), amongst others. In the context of scale discussed above, these authors illustrate a wide variety of geological and geomorphological features of geoheritage significance, and from their examples it is clear that there are sites of geoheritage significance that occur at various scales.

The Australia Heritage Commission (1990) partly dealt with scale in geological/landform units by assigning three levels, as follows: large scale (e.g., Central Plateau of Tasmania), medium scale (e.g., Lake George, or the Glasshouse Mountains), and small scale (e.g., Hallett Cove, Geikie Gorge, or Quincan Crater). Joyce (1995) presented these same scales of reference, but implicitly added a further smaller scale, that of an individual site, such as a road cutting.

Scale was more formally addressed in a series of classification papers on coastal and wetland landforms by Semeniuk and co-workers (Semeniuk 1986a; C A Semeniuk 1987; Semeniuk et al 1989). The landforms in these works were described in frames of reference of fixed sizes, using terms for frames of reference such as regional, large, medium, small, and fine (Semeniuk 1986a; Semeniuk et al. 1989), or megascale, macroscale, mesoscale, microscale, and leptoscale (C A Semeniuk 1987). These frames of reference (modified after Semeniuk 1986a) can be used to describe sites of geoheritage significance. Table 2.2 defines these scales of reference, and provides some examples of geological features at these scales.

### Table 2.2: Definition of the various scales of reference, with examples

<table>
<thead>
<tr>
<th>Scale term</th>
<th>Frame of reference</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional scale</td>
<td>100 km x 100 km or larger</td>
<td>mountain range scale or drainage basin scale: Dampier Archipelago complex</td>
</tr>
<tr>
<td>Large scale</td>
<td>10 km x 10 km</td>
<td>large outcrop scale: limestone barrier at Port Hedland</td>
</tr>
<tr>
<td>Medium scale</td>
<td>1 km x 1 km</td>
<td>small mesas and adjoining plain</td>
</tr>
<tr>
<td>Small scale</td>
<td>10-100 m x 10-100 m</td>
<td>outcrop scale: such as local cliff face exposure</td>
</tr>
<tr>
<td>Fine scale</td>
<td>1 m x 1 m</td>
<td>bedding scale: such as fossils in a shelly lens</td>
</tr>
<tr>
<td>Very fine scale</td>
<td>1 mm x 1 mm, or smaller</td>
<td>crystal features</td>
</tr>
</tbody>
</table>

Sites of geoheritage significance can include features that range in size from crystals to geological features at the scale of mountains and landscapes. This size range and processes/products at various scales also occur in the coastal zone, with features ranging from micro-pinnacles (also termed “lapiés” by some authors; cf. Guilleher 1953; Paskoff 2005), tafoni, etched surfaces, and smoothed surfaces, to specific types of cliffs, to large coastal (depositional) systems such as deltas. Scale is formally addressed in terms of frames of reference of fixed sizes, using regional, large, medium, small, and fine scales, or megascale (= regional), macroscale (= large), mesoscale (= medium), microscale (= small), and leptoscale (= fine). The frame of reference is used to denote those features evident at that particular scale. Cross-lamination, sedimentary layering, lamination, bubble sand, shell layers, tafoni, micro-pinnacles, etched surfaces, and smoothed surfaces are evident within a 1 m x 1 m frame of reference and smaller, while larger cliff faces, shoreline benches and sandy spits are evident within a 10 m x 10 m or 100 m x 100 m frame of reference.
An alternative to using fixed scales of reference is a qualitative approach using terms such as montane scale or drainage basin scale, large outcrop scale, bedding scale, and crystal scale. A selection of various geological and geomorphological phenomena occurring at these qualitative scales is presented in Table 2.3, graded to illustrate the range of scales, and the variety of phenomena that occur at these different scales. The range of scale of geological features encompassed by geoheritage is conceptually illustrated in Figure 2.2 (drawn from Brox & Semeniuk 2007). All scales of geological phenomena need to be addressed in assessing sites of geoheritage significance.

Table 2.3: Examples of geological phenomena at different qualitative scales

<table>
<thead>
<tr>
<th>Mountain range scale or drainage basin scale = regional and large scale of Table 2.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Grand Canyon (Holmes 1966), geomorphologically illustrating an entrenched river meander cutting down to a new base-level, pacing uplift of a plateau, and geologically illustrating unconformities, and a sequence from Precambrian into the Palaeozoic</td>
</tr>
<tr>
<td>Archaean craton structure, folded greenstones, and Proterozoic dykes in the Pilbara Craton (Hickman 1983; Griffin 1990), geologically illustrating a complex array of rounded intrusive granitoids rimmed by greenstones, and cross-cut by a variety of younger dykes</td>
</tr>
<tr>
<td>Linear dune fields from the Great Sandy Desert (Veevers &amp; Wells 1961), geomorphologically illustrating a complex variety of dune forms in this desert from straight linear, to branched, to tuning fork</td>
</tr>
<tr>
<td>Large outcrop scale = large, medium and small scale of Table 2.2</td>
</tr>
<tr>
<td>Hutton’s unconformity, at Jedburgh (Hutton 1795, cited in Dean 1992), a classic location showing the cycle of deposition, induration, upheaval, planation, and further deposition in the Earth’s crust</td>
</tr>
<tr>
<td>Lapworth’s mylonite, along the Moine Thrust (Lapworth 1885; T A Semeniuk 2003), a classic location first used to illustrate the milling of rocks along a major fault</td>
</tr>
<tr>
<td>Interlayered black basalt dykes and granitic gneiss, East Greenland (in Myers 1997), the result of the initial rifting between North America and Europe</td>
</tr>
<tr>
<td>Bedding scale = small and fine scale of Table 2.2</td>
</tr>
<tr>
<td>Dinosaur footprints in the Broome Sandstone at Gantheaume Point near Broome (Geological Survey of Western Australia 1975), illustrating dinosaurs ambulating across tidal flats in the Mesozoic</td>
</tr>
<tr>
<td>Precambrian Ediacara fauna from South Australia (Glaessner 1966), illustrating the oldest invertebrate fauna in the world</td>
</tr>
<tr>
<td>Cambrian fauna from the Burgess Shale in Canada (Gould 1989), illustrating a unique, complex and diverse fauna in Cambrian times</td>
</tr>
<tr>
<td>Crystal scale = fine and very fine scale of Table 2.2</td>
</tr>
<tr>
<td>snowball garnets of Vatterbotten, Sweden (Barker 1998), illustrating rotation under shear of crystals and their spiralling incorporation of surrounding layered matrix</td>
</tr>
<tr>
<td>orbicular structures of the Thorr Granodiorite of Donegal, Ireland (Pitcher 1993) illustrating concentric whisker crystal formation under delicate conditions of growth, diffusion and cooling</td>
</tr>
<tr>
<td>zircons from Jack Hills in Western Australia (Wilde et al. 2001), so far, the oldest crystals in the world, showing the Earth was already solid 50 million years after its formation</td>
</tr>
</tbody>
</table>

The various scales of geological features illustrated in Figure 2.2 that may be of geoheritage significance are intended to convey the notion that the importance of a geological feature can be at the terrane scale (in this example, granite domes in the Pilbara Region of Western Australia provide an example of terrane-scale) but can range in scale down to the cliff, bedding or hand-sized rock, and ultimately to the crystal aggregate and individual crystal. These matters are important because the full gamut of scale in geoconservation, to date, has not been systematically addressed. In many geological reconstructions of Earth history, the analysis may begin at the crystal scale (cf. Logan 1974; Hobbs et al 1976; Barker 1998), as well as encompassing larger frames of reference (using structural and metamorphic examples for the concept of the employment of increasing scale, see Turner & Weiss 1963, Hobbs et al 1976; Wilson 1982; Nicholas 1987; Davis & Reynolds 1996; and Barker 1998).
The matter of significance

Significance in geoheritage and geoconservation is the assigning of a value to a natural geological or geomorphological feature. The Oxford Dictionary defines the word significance as the quality of being worthy of attention (Simpson & Weiner 1989).

While significance is noted in many works dealing with geoconservation, the various levels of significance, i.e., international, national, state-wide, regional, to local, has not been adequately addressed or defined. Significance at international and national level particularly has not been adequately dealt with globally, in part probably as a result of a historical accident relating to what constitutes international and national where many European countries are national entities and yet fall within the scale of intra-national if viewed at a continental scale i.e., if they all can be included within the State of Western Australia whose geological features at state level of significance would be international significance in Europe (see discussion later)\(^1\). Level of significance is a matter that needs to be addressed in classification and site selection, and needs to be incorporated into any planning and management strategy so that geoconservation can be addressed in local and regional issues, as well as the axiomatic protection of sites of international and national importance.

The level of importance attributed to a given feature of geoheritage significance, regardless of scale, is related to one of two factors: 1. how frequent, or common, or rare is the feature within a scale of reference; and 2. how important is the feature intrinsically (this will also include a particular phenomenon or event) or culturally.

If a given geological feature is common at the local scale, and is similarly common everywhere throughout the region, and everywhere throughout the nation, and occurs generally everywhere throughout the globe, then that feature is not significant locally, regionally, nationally or globally. Calcite crystals cementing dune sand are an example of such a feature, and their occurrence throughout an area, locally, regionally, nationally, and globally is not significant. Similarly, but on a larger scale, aeolian cross lamination in Pleistocene calcarenite, such as in the coastal zone of the Swan Coastal Plain and the offshore limestone islands, southwestern Australia (Fairbridge 1950; Semeniuk & Johnson 1985; Playford 1988) is another example: this feature is common throughout many areas (McKee & Ward 1983), locally, regionally, nationally, and globally, and hence is not significant. If, on the other hand, a geological feature occurs once or infrequently at the local scale, but occurs at that same frequency through the regional, and nationally, and globally, then it is feature-significant at the local scale. However, if a geological feature occurs once or a few times within a nation (e.g., inland stromatolites occurring at Lake Clifton, Lake Richmond, Lake Thetis, and some lakes in the Eyre Peninsula in South Australia), then it is of national significance. And if a geological feature occurs only once, or a few times world-wide (the tidal flat stromatolites of Shark Bay, and the zircon crystals of Jack Hills), then it is a feature of global significance. These notions are summarised diagrammatically in Figure 2.3. This procedure of assessing significance is semi-quantitative.

The examples in Figure 2.3A illustrate a range of geological features both at different levels of significance and at various scales. The geological features used to illustrate examples of international significance are the large scale features of the Grand Canyon (USA), El Capitan in the Guadalupe

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\(^1\) The term 'state’ in ‘state-wide’ here refers to a subdivision of nation into smaller administrative and political blocks, and has a different meaning to the term ‘state’ as used in dual word ‘nation-state’. In Australia, for instance, there are six states and two administrative territories that is the equivalent to a state, and state-wide refers to a feature or attribute that occurs within a ‘state’. For the term ‘regional’, in the fields of physical geography, geology, ecology, and biogeography, ‘regional’ generally refers to large areas as based on boundaries determined by natural features such as geological systems (e.g., a metamorphic rock terrane), ecosystem types or biotopes, drainage basins, mountain ranges, soil types. Semeniuk (1986a) uses the term ‘region’ with distinct and defined scalar connotations. In this Thesis, in the context of determining significance levels, ‘regional’ is used to refer to large areas that have natural boundaries, or that represent large administrative areas.
Mountains (USA), carbonate mounds at Pamukkale (Turkey), an emerged salt dome in the Zagros Mountains (Iran), the Shark Bay coastal and marine system (Western Australia), and a small-scale feature, *viz.*, a Precambrian fossil from the Ediacara fauna from the Rawsleys Quartzite (South Australia). Figure 2.3B illustrates the notion of national significance by using inselbergs and intracontinental volcanic landscapes erodionally derived from Cainozoic volcanoes. Figure 2.3C illustrates some examples of well-preserved cross-lamination in Pleistocene aelolianites from a number of locations spanning the north-to-south extent of the biogenic aelolianite suite in southern western Australia.

In addition to the geological features noted above being considered common, or uncommon, or rare, many also have intrinsic value, *e.g.*, tidal flat stromatolites of Shark Bay, zircon crystals of Jack Hills, carbonate mounds at Pamukkale, the Ediacara fauna, amongst others.

A geological feature may assume global significance because it is a cultural site of significance (as noted earlier and to be expanded later, ‘cultural’ refers to ideas, customs, and social behaviour of local Traditional Owners or Indigenous groups, a local community, or a scientific community). Even if the geological feature is perhaps common throughout the world, the location of its first description may become a site of geoheritage significance for two reasons: it provides a type site of what is meant by the description provided by the first researcher, and secondly it may represent a location of scientific historical interest. Lapworth’s mylonite site along the Moine Thrust at Knockan Crag in Scotland (Lapworth 1885; T A Semeniuk 2003) is an example of such a location. Thrust zones, and their associated mylonites, are common around the globe, but the Moine Thrust at Knockan Crag provides a specific historical location wherein Lapworth (1885) first reconstructed the dynamic metamorphic processes of milling of rocks to form finely laminated fault rocks (the mylonites). It is a site where researchers can visit and revisit to test the definition, refine or redefine terms, and calibrate their notion of fault rocks, and it is a site of scientific historical (cultural) significance. Conserving sites of scientific historical significance is the equivalent to enshrining, as culturally significant, the site of the metaphorical or actual apple tree (if it still existed) that, as legend would have it, provided Sir Isaac Newton with the idea of gravity (Keening 1998; National Trust 2006).

A number of authors have attempted to address the matter of significance in relation to geoheritage and geoconservation (Joyce 1995, Dixon 1996, Semeniuk & C A Semeniuk 2001, Sharples 2002). Joyce (1995) discusses the use of the term *significance* in assessing geological heritage. Dictionary definitions for “significance” show inter-related terms such as “outstanding”, and “representative”, and stipulate a meaning of “import of something”, “importance”, “of consequence”. Joyce (1995) also suggests that sites of geoheritage significance can lie on a scale between “highly significant” to “of little or no significance”. However, Joyce (1995) does not provide examples of what is considered as significant in geoconservation, and there is no detailed explanation of the grading of “significance”.

Kiernan (1990) discussed use of the term *significance* in relation to geomorphology, proposing that significance be addressed from a number of perspectives: why is a landform significant? to whom is it significant? at what scale is it significant? and is its significance likely to be temporary or permanent? Kiernan (1990) suggests that two principal approaches can be taken with regard to significance: either landforms are outstanding examples, or representative examples. However, Kiernan (1990) also emphasises that while it is important to protect outstanding examples of particular landforms, it is likely to result in neglect of the more common types, which in time also will become rare.

The Australian Heritage Commission (1990; abolished in 2003) set out criteria to assess sites that are significant enough to be placed on the Register of the National Estate for Australia, but there were several deficiencies: for instance, there is no explanation of what is considered to be significant (*i.e.*, the criteria were broadly worded, and there was no yardstick or comparative measure with wording such as “the geological site must be a unique feature in Australia to be considered as highly significant” to enable readers to positively identify sites of significance); there are no comparative examples of significance, nor grading of significance from “highly significant” to “moderately significant” to “of low significance”, and no reference base to review and compare the attributes of sites already in the conservation estate with sites to be added or, in some cases, replaced with better
examples. Later, the Australian Heritage Commission (Cairnes 1998) dealt with significance, identifying it as the process of assessing the importance of a site. The Australian Heritage Commission (1990) identified types of heritage significance (viz., natural, indigenous, and historic cultural), providing criteria of significance (e.g., cultural phases and the evolution of ecosystems; rarity; research, teaching; representativeness; amongst others, as found in the now-extinguished *Australian Heritage Commission Act 1975*) which can be individually graded 1-10, and outlining how “statements of significance” could be prepared.

Places of national importance are protected under the Environment Protection and Biodiversity Conservation Act 1999 (the EPBC Act), and the Minister for the Environment, Heritage and the Arts (the Minister) is responsible for the National Heritage List. Amendments to the EPBC Act in 2003 define the Australian Government’s role in relation to Natural heritage. The provisions in the EPBC Act and Environment Protection and Biodiversity Conservation Regulations govern the National Heritage listing process. All decisions as to whether a place has National Heritage values must be made by reference to the EPBC Act and the Environment Protection and Biodiversity Conservation Regulations. Guidelines deal with the interpretation of the National Heritage provisions in the EPBC Act and the Regulations, and outline a number of tools and approaches that may be taken to assess places by the Australian Heritage Council for inclusion in the National Heritage List. The Guidelines have no statutory force under the EPBC Act or the *Australian Heritage Council Act 2003*. Decisions in relation to assessment of places may have regard to the Guidelines. The decision whether a place has National Heritage value must, in each case, be based on the application of the statutory provisions as interpreted by the Australian Heritage Council of the day (hereafter referred to as the ‘Council’).

Using the same criteria as the Australian Heritage Commission, to be included on the National Heritage list, a place must meet 9 heritage criteria and “significance thresholds”. Statutory listings are devices for identifying and protecting places we wish to keep. They are the primary means by which the heritage values of such places are articulated, and for guiding the management of these places.

The National Heritage criteria against which the heritage values of a place are assessed are (Australian Heritage Commission 1990):

a. the place has outstanding heritage value to the nation because of the place's importance in the course, or pattern, of Australia's natural or cultural history

b. the place has outstanding heritage value to the nation because of the place's possession of uncommon, rare or endangered aspects of Australia's natural or cultural history

c. the place has outstanding heritage value to the nation because of the place's potential to yield information that will contribute to an understanding of Australia's natural or cultural history

d. the place has outstanding heritage value to the nation because of the place's importance in demonstrating the principal characteristics of:

   i. a class of Australia's natural or cultural places; or
   ii. a class of Australia's natural or cultural environments

e. the place has outstanding heritage value to the nation because of the place's importance in exhibiting particular aesthetic characteristics valued by a community or cultural group

f. the place has outstanding heritage value to the nation because of the place's importance in demonstrating a high degree of creative or technical achievement at a particular period

g. the place has outstanding heritage value to the nation because of the place's strong or special association with a particular community or cultural group for social, cultural or spiritual reasons

h. the place has outstanding heritage value to the nation because of the place's special association with the life or works of a person, or group of persons, of importance in Australia's natural or cultural history

i. the place has outstanding heritage value to the nation because of the place's importance as part of Indigenous tradition
Note: The cultural aspect of a criterion means the Indigenous cultural aspect, the non-Indigenous cultural aspect, or both.

As well as assessing a place against criteria for its heritage value, the Council is also required to apply a significance threshold. This test helps the Council to judge the level of significance of a place’s heritage value by asking ‘how important are these values?’

To reach the threshold for the National Heritage List, a place must have ‘outstanding’ heritage value to the nation. This means that it must be important to the Australian community as a whole. As a means of determining whether a place has outstanding heritage values, it is compared to other similar types of places. However, as with the assessment process used by the Australian Heritage Commission, while the Australian National Heritage Assessment Tool (ANHAT) was developed to identify sites of natural significance, it only is only applicable to biodiversity and not geoheritage. There is no method or comparative measure with wording such as “the geological site must be a unique feature in Australia to be considered as highly significant.”

For the Environment and Heritage Legislation Amendment Act (No. 1) (Heritage Amendment Act 2003; to include ‘national heritage’ as a new matter of National Environmental Significance and to protect listed places to the fullest extent under the Constitution; for the 2003 and 2007 amendments to the Environment Protection and Biodiversity Conservation Act 1999 see Appendix 1.

From the literature it is clear that while many authors identify significance as a factor in assessment (e.g., Joyce & King 1980; Davey & White 1986; Dixon & Pemberton 1991; Joyce 1995; Sharples 2002; and the Australian Heritage Council), and some set up criteria to assess whether a geological or a geomorphological site is significant, the approach in the early phases taken by these authors appears to be one of an “either/or” situation, i.e., either a given site qualifies to be significant or it doesn’t. Later, when the term significance was more rigorously explored (Kiernan 1990; Australian Heritage Commission 1998; Sharples 2002), the criteria for grading and allocation of levels of significance still were not defined. The assessment of significance remained a subjective process.

Semeniuk (1986b) and Semeniuk & C A Semeniuk (1987, 2001) directly addressed the issue of significance in their work on the conservation of mangrove coasts, inland wetlands, and sites of geoheritage importance on the Swan Coastal Plain, respectively, by developing a practical tool in providing scales of significance and criteria for their recognition. Their work, in principle, is applicable to assessing sites of geoheritage significance in general, and in providing grades of significance. Significance can be ranked according to levels or degrees. Amalgamating the works of Semeniuk & C A Semeniuk (1987, 2001)), five levels of significance are recognised:

- International
- National
- State-wide
- Regional
- Local

Sharples (2002), summarising work by Rosengren (1984) and others, has presented a similar grading, but added a category of unknown significance where insufficient information is available to make an assessment. While the levels of significance listed above have been used globally, nationally in Australia, and within Western Australia, generally there is no definition of these terms except by the Semeniuk and Sharples (references cited above). An expansion of the definition of these terms according to these levels of significance, based on Semeniuk (1986b), Semeniuk & C A Semeniuk (1987, 2001), Sharples (2002) and Hogan & Thorsell (2005), with examples of natural features globally, nationally and within Western Australia (Geological Survey of Western Australia 1975; Australian Heritage Commission 2005, UNESCO 2002), are presented in Table 2.4.
Table 2.4: Definitions and examples of levels of significance for sites of geoheritage significance\(^1\) (note that the size of these features of geoheritage significance ranges from the very large scale (e.g., The Everglades) to crystals (Jack Hills zircons))

<table>
<thead>
<tr>
<th>Significance</th>
<th>Definition and criteria</th>
<th>Global, Australian, and Western Australian Examples</th>
<th>Rationale for assigning level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>International</td>
<td>only one, or a few, or the best example of a given feature occurring globally, hence it is globally unique, rare, or uncommon; or performs a function in a global network</td>
<td>1. The Everglades, Florida, USA; 2. sinter and springs, Pamukkale, Turkey 3. tidal flat columnar stromatolites, Shark Bay; WA 4. Jack Hills zircons, WA</td>
<td>globally unique systems or geological features</td>
</tr>
<tr>
<td>National</td>
<td>while it may be present elsewhere globally, only one, or a few, or the best example of a given feature occurring nationally; hence it is nationally unique, rare, or uncommon; or performs a function in a national network(^2)</td>
<td>1. Permian/Precambrian unconformity, Halletts Cove, SA 2. volcanic landforms, Warrumbungle Ranges, NSW(^2) 3. Murphy’s Haystacks, Eyre Peninsula, SA(^2) 4. Wave Rock, near Hyden, WA 5. The Pinnacles at Cervantes, WA</td>
<td>unique systems or geological features within a given nation, or performs a function in a national network</td>
</tr>
<tr>
<td>State-wide</td>
<td>while it may be present elsewhere globally or nationally, only one, or a few, or the best example of a given feature occurs state-wide; hence in the state it is rare, or uncommon; or performs a function in a sub-national network</td>
<td>1. karst features in southern Western Australia 2. the buttes in the NW Pilbara region, WA 3. Pleistocene rocky shore stratigraphy, Perth coast, WA 4. orbicular granite, Mount Magnet, WA</td>
<td>unique systems or geological features within the state</td>
</tr>
<tr>
<td>Regional</td>
<td>while occurring elsewhere globally, nationally, or state-wide, only one, or a few, or the best example of a given feature occurs in the region; hence it is uncommon or rare in the region; or performs a function in a regional network</td>
<td>1. Lake Gnangara on the Swan Coastal Plain, WA 2. conglomerate outcrop at Nannup, WA 3. Bunbury Basalt outcrop at Bunbury, WA 4. mesa formations, southwestern Pilbara region, WA 5. specular haematite crystals, Koolyanobbing, WA</td>
<td>important systems or geological features in the region, and for the coastal limestone, exposure of atypical stratigraphy</td>
</tr>
<tr>
<td>Local</td>
<td>the natural history feature is important only to the local community</td>
<td>limestone cliffs along the Perth coast, illustrating well-formed cross-lamination in the limestone</td>
<td>important to the local community and schools</td>
</tr>
</tbody>
</table>

\(^1\) This list is not intended to imply that the full range of features noted/listed here have been formally recognised as significant. It provides examples of the level of significance that should be attached to the nominated feature.

\(^2\) They are part of a national network of inter-related sites, e.g., an ensemble of volcanoes in a chain across the nation illustrating palaeo-volcanology, the change in character of inselbergs across a climate gradient, or a chain of disconnected wetlands in a large drainage basin.
In the context of the levels of significance discussed above, Figure 2.1 is revisited to provide a measure of assessment of the geoheritage significance of the features illustrated therein.

Cape Range is a large scale geological and geomorphic feature of international significance (Figure 2.1A). It illustrates a coastal landscape developed by Cainozoic tectonism (generating a barrier-and-gulf coastal form along the interface between the Carnarvon Basin and the coastal plain of the Pilbara Coast; Semeniuk 1993), with subsequent drainage superimposed on a limestone terrain. It also illustrates terracing due to progressive uplift of various Pleistocene marine sediments and coral reefs (van de Graaff et al. 1976). And it contains a karst system that is a habitat to stygofauna. Its geological characteristics have been recognised as contributing to its values as a national park (Conservation & Land Management 2005). Recently, it was proposed as part of a World Heritage listing by the Department of Environment & Conservation (World Heritage Consultative Committee 2004).

The linear dune field in the Great Sandy Desert (Veevers & Wells 1961) is a desert geomorphic feature of aeolian landforms (Figure 2.1B). They are the dominant linear dune field in the state. From a national perspective, linear dunes are present through Australia (King 1956; Jennings 1968), and in terms of continuous extent of area covered, and clarity of development, the dunes in the Great Sandy Desert comprise one third of the best developed, and best-preserved linear dune fields Australia-wide. The linear dunes in the Great Sandy Desert, however, carry an additional significant feature – they reside in a modern basin (the Canning Basin), and their seaward extremities interface and stratigraphically interact with sediments of the coastal zone, as described by Jennings (1975) and Semeniuk (1982). Additionally, the dune field of the Great Sandy Desert falls into the category of broad crested linear dunes (Wasson et al. 1988), and comprises one of the two major concentrations of such dunes in Australia, the other being in the Northern Territory (see figure 5 of Wasson et al. 1988). These latter aspects on their own render them as geomorphic features of State-wide significance.

The recurved spit of small shells (the Hamelin Coquina; Logan et al. 1970) illustrates a coastal geomorphic and stratigraphic feature of global significance (Figure 2.1C). Shell accumulations peripheral to hypersaline basins are unusual globally, and prograded coastal plains formed by such shell accumulations are equally unusual. As part of the Shark Bay World Heritage site, the lithologic, stratigraphic, and diagenetic history of the Hamelin Coquina (Logan et al. 1970; Logan 1974) alone serves as a globally unique and significant classroom in sedimentology, stratigraphy and diagenesis.

The buttes in the north-western Pilbara, illustrate geomorphic and geologic features (Figure 2.1D). The buttes are developed from the hard capping of Mesozoic sedimentary rock that unconformably rests on Precambrian granite, effectively highlighting the stratigraphic interface between sedimentary deposits of the Canning Basin and the Precambrian rocks of the Pilbara Craton. This unconformity is located circa 30 m above sea level. The ensemble of geological and geomorphic features being localised only in this situation at the contact of the Canning Basin and the Pilbara Craton, and the elevated height of the unconformity renders these buttes as of state-wide significance.

The Pinnacles at Cervantes illustrate a geological and geomorphic feature of National significance (Figure 2.1E). While limestone, calcreted pipes, and yellow sand cover are common along the coastal fringe of south-western Australia, the occurrence of exhumed calcreted pipes to form an extensive pinnacle landscape is unique in Western Australia. Further, the landscape is not developed along the eastern board of Australia, and also not developed in South Australia, where age-equivalent and lithologically equivalent coastal limestones occur. This makes The Pinnacles a feature of national significance.

The folded laminated ironstone and chert, developed along a decollement in the rocks of the Brockman Iron Formation in Hamersley Gorge, Karijini, in the Pilbara region is a feature of regional significance (Figure 2.1F). It is a well-exposed example of such a fold, and is useful to structural geologists in reconstructing the tectonic history of the Hamersley Group. The exposure in the gorge also provides access to contacts, whereas outcrops of such decollements and their associated folds are not so well exposed throughout the region.
The outcrop of Bunbury Basalt at Bunbury (Figure 2.1G) provides exposure of a valley fill of this Cretaceous basalt, where normally it remains largely buried under the Leederville Formation (Playford et al. 1976). While there are more extensive and larger outcrops of this basalt along the southern coast of Western Australia, the outcrop along the coast at Bunbury illustrates the narrow outcrop of a valley form body extending to the northwest. In terms of geomorphology, the outcrop of the basalt at Bunbury is low in elevation relative to sea level, and shows coastal geomorphic features of basalt subject to coastal erosion and weathering resulting in shore platforms and specific microtopography. The outcrop at Bunbury is also the type location of the formation. The outcrop of Bunbury Basalt at Bunbury is a site of regional geoheritage significance.

The folded metamorphic rock, in the Owingup area, illustrates isoclinally folded gneissic amphibolite (Figure 2.1H). As a structural and metamorphic feature it is locally significant in that it is a well-developed example of this type of folding and rock type exposed along the coast by marine erosion and marine weathering, and it can assist structural geologists in reconstruction metamorphic and structural history along the south coast of Western Australia.

The scale at which a given geological feature is assessed as significant should not imply that all features at that site at other scales of reference are of equal importance. For instance, the landforms in the Jack Hills area are not of international, national, or state-wide significance, but the zircon crystals therein are internationally significant. Conversely, the inselberg at Uluru and the fact that this large landform is composed of vertically dipping feldspathic sandstone is of international significance, but the individual feldspar grains comprising the sandstone are not significant, as feldspathic sandstone is common globally, nationally and state-wide.

**Categories of sites of geoheritage significance**

Sites of geoheritage significance can be classified as to category of site. Four categories are recognised as end-member types. As will be discussed later in this section, there can be some degree of overlap between categories, and some sites may be assigned to two or more categories. It is important to assign sites of geoheritage significance to the categories because when comparisons are made, and levels of assessments are carried out, it is important that sites are compared and assessed against similar categories. The four categories are:

1. Reference sites, teaching sites, type localities, type examples
2. Culturally significant sites.
3. Geohistorical sites
4. Modern landscapes where active processes are operating

The four categories of sites of geoheritage significance are very different in their scope as will be described below.

1. **Reference sites, teaching sites, type localities, type examples**

   These are sites that are equivalent to the type species in the biological sciences. They provide reference and teaching localities, and standards for future researchers and students. In the stratigraphic sciences, they provide the type section of what constitutes a formation. Often these sites are also some of the first-recorded and preserved sites of geoheritage significance, and address type stratigraphic and soil locations, type fossil locations, and geomorphic locations as standards for Earth scientists for research and education.

2. **Culturally significant sites.**

   Culturally significant sites are of several types, where the adjective ‘cultural’ relates to the ideas, customs, symbolic, mythological, religious, and social behaviour of a society such as a local Indigenous group, or local community, or importance to a scientific community:
1. These are sites of cultural significance to the scientific community, e.g., sites where geological principles were first explored and explained (in addition to being of scientific importance and reference sites, Hutton’s unconformity site at Siccar Point and Lapworth’s mylonite site along the Moine Thrust are typical and classic examples; these sites may not be the best example of a geological phenomenon globally but represent, in the history of Science, the first example of the description and conceptualization of the features.

2. Culturally significant sites may have an indigenous aspect, i.e., the geological feature may not be globally or nationally significant but is of great importance to the local people; The Devil’s Marbles in Northern Territory is an example (they are a series of red-brown granite tors, that through weathering and erosion have become isolated, near-spherical large blocks (“marbles”) balancing on the granite pavement from which they were derived - such topographic features are not rare but they are of immense importance to the local Traditional Owners);

3. Culturally significant sites may have a societal aspect, where an iconic and/or aesthetic landscape or rock feature is valued by the community, or is a tourist attraction, e.g., The Twelve Apostles Look-out in coastal Victoria, Dog Rock in Albany, Western Australia, and The Rock of Ages in Port Hedland, Western Australia.

3. Geohistorical sites
Geohistorical sites are those where former Earth processes and Earth history can be inferred and reconstructed from outcrops such as cliffs. The Grand Canyon serves as an example of this category in that it exhibits a classic stratigraphic sequence and geomorphology to enable reconstruction of Earth history. Sea cliffs, or other types of coastal outcrops, that expose ancient sequences (ranging from Precambrian in age such as the sequences exposed in cliffs along the central Pilbara Coast, to cliffs exposing Mesozoic or Cainozoic sequences such as those along the edge of the Sydney Basin in New South Wales, or the edge of the Nullarbor Plain, to cliffs of Quaternary limestones as exposed at Zuytdorp Cliffs), clearly represent the category of geohistorical sites in which there are exposures from which the history of the Earth or the processes within the Earth in the past can be reconstructed.

4. Modern landscapes where active processes are operating
This category of site relates to modern landscapes where active processes are operating. These sites provide information about extant Earth processes per se, and are useful for interpreting ancient sequences.

For the category of modern, active landscapes, Sharples (1995) expanded the original idea of geoheritage to include areas of dynamic geological processes. This could include environments such as mobile coastal dunes, or fluvial systems with annual or episodic floods. However, this notion is explored further for this Thesis as it has relevance to assigning coastal types to categories of modern, active landscapes, or to geohistorical sites. These two categories can grade into each other.

Landscapes can vary gradationally from being very active (e.g., mobile inland-ingressing parabolic dunes), to episodically active (e.g., floods in riverine systems in arid zones), to largely now inactive, but intermittently active over the Holocene (e.g., arid zone fluvial systems, or prograded coastal plains). Further, where there is a combination of active geomorphic, sedimentological and diagenetic processes operating in an area, one of the processes may be episodic, another intermittent, and the third ongoing, and each may have different rates and intensities when active, and various expressions in a gradient normal to the coast. For purposes of this Thesis, for separating geohistorical sites from active modern landscapes, this temporal and spatial gradation in landscape activity and dynamism leads on to a discussion of what constitutes dynamic process, and how far inland should the idea of “dynamic process” for coastal geoheritage be taken.

The majority of coastal scientists would agree that mobile, landward-ingressing, coastal parabolic dunes accord with the notion of “dynamic”. Similarly, relatively rapidly accreting coasts, such as the Gascoyne Delta (Johnson 1982) and Point Becher (Searle et al. 1988), or eroding coasts, retreating at, say, 1 m per annum, as recorded in cliffs cut into mud in King Sound (Semeniuk 1981a) and along the
sandy seafront of the Leschenault Peninsula (Semeniuk & Meagher 1981a), and the retreating cliff along the edge of the Nullarbor Plain with its continual development and erosion of shoreline talus (breccia) deposits, would also constitute dynamic environments where processes are extant. Slow retreat of limestone rocky shores, measured in rates of < 1 mm per annum (Hodgkin 1964), under the action of algae-grazing molluscs, other forms of bioerosion, wave abrasion, or chemical corrosion also could be considered as dynamic, albeit at reduced rates appropriately related to their climatic, biological, and environmental setting. In this latter example, the coast is still actively eroding, but not so conspicuously.

This poses the question of how rapid a process must be for it to be designated as *dynamic*. For instance, for erosional coasts, various studies on different materials and rock types under different processes show varying rates of erosion (Hodgkin 1964; Gill 1973; Semeniuk & Meagher 1981a; Semeniuk 1981a; May & Heeps 1985) and, conversely, for prograding coasts, there are varied rates of accretion (for deltas, see Fisk 1961; for cuspate forelands, see Searle et al. 1988; for arid-zone coastal sedimentation, see Semeniuk 1996a and Semeniuk 2008). In this Thesis, all extant processes at the coast are classed as dynamic, regardless of whether they are rapid and visually conspicuous, or extremely slow, but nonetheless effecting change in landforms through agencies of erosion or sedimentation, or where they result in diagenetic products. That is, it is Holocene coastal processes *in action* that constitute a dynamic environment, or it is where processes still contribute to an ongoing developing system.

Coastal processes can change spatially and temporally in their style, effect, and intensity. Spatially, they may be conspicuous and marked at the coast, and change inland because there is a gradient in hydrochemistry, or because of decreasing intensity (*e.g.*, decrease in seabreeze velocity), or change in processes (*e.g.*, marine water diagenesis giving way to fresh-water diagenesis). Dunes ingressing inland under the effect of coastal winds may be subject to marine/brackish water diagenesis at the coast and fresh-water diagenesis in inland locations.

For modern, active (coastal) landscapes, the main ubiquitous processes include sedimentation, erosion, biogenic processes, and diagenesis, processes which may be continually operating, or intermittently operating, or have the potential to be reactivated. In the case of prograding coasts, generally the most dynamic portion of the landscape is the seaward part or the seaward edge of a prograded/prograding plain, with a stranding of the earlier deposits inland, and a consequent decrease in activity of coastal processes towards inland. The attendant effect is that processes of sedimentation and erosion may/will progressively decrease inland. Three coastal landscapes and their processes are described below to demonstrate the extent that coastal active processes may extend inland: a prograding tidal flat, a prograding beach ridge plain, and coastal barrier dunes.

In the case of prograding tidal flats, the active processes are largely sedimentation, biogenic activity, and diagenesis. The seaward parts of tidal flats involve accumulation/accretion and biogenic activity on the low intertidal to high intertidal flats, with development of stranded flats that are inundated only on the highest (equinocial) tides and by storm waters. But for such environments, while there will be annual inundation by the highest tides and storm water, these tidal flats also are subjected to on-going coastal hydrochemical, groundwater, and other processes (that are graded from the level of the lowest tidal level to that of the highest tide) that diagenetically imprint on the stranded flats (Logan 1974; Semeniuk 1981a, 1981b, 2008). In the case of prograding beach-ridge plains, the main processes are sedimentation, intermittent erosion, and diagenesis. With progradation, the beach surface accretes to become incipient beach ridges, and beach ridges become emergent above the level of the highest tides and storms by vertical aeolian accretion of sand ridges (Searle et al. 1988; Semeniuk et al. 1989; C A Semeniuk 2007). Thus, in contrast to tidal flat systems, to some extent there is a decrease in coastal effects in regard to sedimentation and accumulation in stranded parts of such systems. However, with beach-ridge plains, the coastal zone may later be subjected to coastal wind erosion and sand remobilisation (forming inland-transgressing parabolic dunes), originating from the coast zone itself, and still is within the realm of active coastal processes though this may be staggered in time and space. In this case, the entire package of seaward-edge processes of sedimentation and any concurrent mobilisation of dunes towards inland, the reactivation of inland ingressing dunes, wind erosion of stranded beach ridges and dunes, are all part of the ensemble of *modern, active landscapes where*...
dynamic processes are operating, as distinct from terrains of Quaternary limestone, or older rock sequences that have not been actively formed as part of the modern landscape. Similarly, any diagenesis effected on the beach-ridge plain is part of the same ensemble of modern, active landscapes where dynamic processes are operating. The same principles apply to coastal barrier dunes. The most active zone is the seaward edge and the coastal zone immediate to the shore. However, for coastal barrier dunes, the coastal zone may later be subjected to wind erosion and sand remobilisation, forming inland-transgressing parabolic dunes, and still is within the realm of active coastal processes which may be staggered in time and space (Semeniuk & Meagher 1981a). In the case of coastal barrier ridges, the leeward side of the barrier (the side actually most distant from marine environment) may be a zone of dunes actively encroaching into a leeward estuary or a lagoon.

For the examples presented above, prograded tidal flat and beach ridge plains, as well as coastal barrier dunes, are considered to be modern landscapes with dynamic processes, and the plains in particular are the result of active edge-of-sea sedimentation. In older parts of such systems, modern diagenesis and reactivation of dunes still place these environments within the category of active and extant. However, on the oldest parts of such systems, the landscapes may change from being modern and active to geohistorical sites where there are exposures in cliffs and outcrops recording the Holocene history of the Earth, or the past Holocene processes within the Earth.

Many sites can be assigned to more than one category. A rocky cliff face exposed on an actively eroding coast that manifests numerous features and processes of modern rocky shore development (i.e., be an example of active processes), may be the type section of a given formation, and may also be a cliff face that provides excellent exposure of a stratigraphic sequence that can be used to reconstruct geological history (i.e., be a site illustrating geohistory); and may be a significant cultural site (e.g., Siccar Point). As such, it accords with being a stratigraphic type locality, a culturally significant site, a geohistorical site to unravel Earth history, and a modern landscape where active processes are operating for rocky shore development.

A degree of overlap with the categories can also occur. A good example is provided by Holocene coastal systems where the Holocene coastal landscapes are left stranded by coastal progradation, the modern coastal processes decrease in effect inland, and the modern terrestrial processes increase in effect inland. The inland part of the prograded terrain becomes more isolated from the processes that generated it. At some point in the gradient from the coastal zone itself to inland where coastal effects are still manifest but with fewer processes, to far inland where coastal effects of onshore winds are minimal to nonexistent, there is a decrease in marine-effected processes and increase in terrestrial processes (Figure 2.4). At the coast there is wave action, tides, marine cementation, diagenesis effected by fresh-water seepage, anoxic pyritisation under marine conditions, marine biogenesis (shell production), marine bioturbation, evaporation, bubble sand development, and some effects of storms. Inland there is no wave action or tides, and some effects from extreme storms, but there is fresh-water cementation, soil development, anoxic pyritisation under freshwater conditions if there is organic matter below the water table, and coastal winds effecting inland dune incursion. This transition passes from a modern active and dynamic coastal landscape replete with active marine and coastal processes to develop landforms, sediments, stratigraphy and diagenetic products to a stable landscape where little active coastal processes are operating. The coastal terrain can be categorised as active landscape and modern processes, the far inland terrain, because of its stratigraphy and relict stranded landforms preserving former coastal processes, can be categorised as a geohistorical site.

In the above examples of gradations, and the inland components of a stranded coastal system, it is important to recognise that they are part of an integrated system, the totality of which is important and any conservation designation should include the gradation and both coastal and inland components of the system.
Geoconservation begins with the identification of geological sites of significance either as single features or as ensembles (that is, as a geological feature, or group of integrated geological features or geological sites). There are various bases for protecting individual geological features, sites, areas, or regions; these include: the protection of type sections and reference locations; sites that illustrate science history, i.e., geohistorically important sites (e.g., Hutton’s unconformity, or Lapworth’s mylonite; Oldroyd and Hamilton 2002); intrinsically important sites such as Jack Hills zircons (Wilde et al., 2001), the Iridium-enriched layer along the Cretaceous/Tertiary boundary (the K/T boundary; also called the K/Pg boundary) in Italy (Alvarez et al., 1980; Alvarez 2009; Newell 2014), the Ediacaran fauna in South Australia (Runnegar 1992), the Burgess Shale in Canada (Morris 1999), the Cotton Castle at Pamukkale in south-west Turkey (Dilsiz 2002; Lécuyer 2014); areas that show active modern processes, and many other one-off localities. While there are various terms for sites of geoheritage significance developed around the World with different degrees of protection and different emphases for their protection, classification of geological sites of geoheritage significance has not been systemically explored and developed for purposes of geoconservation.

Once given sites are identified as significant, they can then be assigned to a category of geoconservation and management. Currently, there is a plethora of names for various types of sites for geoconservation used explicitly or implicitly in referring to sites of geoheritage significance and their geoconservation and management; these include, for example, geological site, geosite, Site of Geological Interest (SGI), Site of Special Scientific Interest (SSSI), geotope, type section, type locality for palaeontology, type locality for minerals, reference site, reference locality, geological monument, monument, geopark, and World Heritage Site. Explicit examples include geological site, geosite, type sections, type locations (for fossils or minerals), and reference sites. Many sites are protected for their geological features although their conservation designation is explicitly not a ‘geoconservation’ site. For instance, some protected areas while encompassing geoconservation do not explicitly focus on geological features in the region (e.g., the Blue Mountains World Heritage Site is conserved for its biodiversity). In addition, definitions and terms for sites of geoconservation may vary in meaning from nation to nation (Brocx 2008).

Also, some important geological sites that should be assigned geoconservation status do not carry with them explicit protection. For instance, a type stratigraphic section, as a reference site, ideally should be a protected geological site, but this generally is not the case. For instance, the type sections along coastal Western Australia for the Herschell Limestone on Rottnest Island, the Becher Sand and Safety Bay Sand at Rockingham (Semieniuk & Searle 1985) and the Mowanjum Sand in King Sound (Semieniuk 1980a) are not explicitly protected by legislation. Some type sections along coastal Western Australia are protected only because they occur in National Parks, Conservation Reserves, or World Heritage Sites that were inscribed for other conservation reasons, e.g., the Carbla Oolite at Goat Point at Shark Bay (Logan et al. 1970), and the various Tertiary to Quaternary formations at Walpole-Nornalup Inlet (Semieniuk et al. 2011) and, as such, are afforded protection because of their land vesting. While some type sections were listed on the Register of the National Estate (RNE), e.g., the Herschell Limestone on Rottnest Island (Playford 1983, 1988; Australian Heritage Database 2014; Geoscience Australia 2014), at the time the RNE was in operation there was no formal legal protection of these sites, and they were not transferred to the National Heritage List for legal protection under the EPBC Act.

The various categories of geoconservation and management also carry with them connotations with respect to scale (e.g., Stratigraphic Type Section versus IUCN conservation categories versus UNESCO Geopark Network versus World Heritage Site). To date, there has been an inadvertent scalar approach to formal geoconservation. Geosites, Sites of Special Scientific Interest, Monuments, reference Sites, type Locations, and geotopes tend to be small scale, involving areas generally less than 100 m x 100 m, and even smaller. Geoparks and World Heritage Sites tend to be larger scale assemblages of geological features.
Geoconservation can involve preservation of single features (specific sites, special sites), or of geological ensembles. The former is where a significant geological feature occurs in isolation, or may have historical or cultural significance. Sites in isolation are formally identified in the British Isles as Sites of Special Scientific Interest, abbreviated as SSSI. For the small scale, two terms could be adopted here: geosite (of Australia) and SSSI (of the British Isles; JNCC 1996), although ‘geosite’ is the preferred term and is more prevalently used in this Thesis and especially in the case studies. Examples (in increasing scale) of geological features, as special sites, occurring in isolation (geosites, or SSSI) include: 1. the Precambrian Ediacaran fauna in a local area in South Australia (though embedded in a geology that is typical and representative of the region and not of great geoheritage significance); 2. the Pleistocene rocky shore at Muderup Rocks (Brocx & Semeniuk 2009a), though the limestone within which it is embedded is typical and representative of the region and not of great geoheritage significance; 3. the fossil forest at Purbeck, British Isles (Davies 1956; West 2011a, 2011b; Cope 2012); and 4. the giant gypsum crystals in Naica, Mexico (Garcia-Ruiz et al. 2007). Examples of geological features, as special sites, having geological, and historical or cultural significance, include Hutton’s unconformity at Siccar Point, and Lapworth’s mylonite along the Moine Thrust. Some locations will have historical importance while their encompassing local geology may not be significant Nationally or Regionally.

Geoconservation of geological ensembles involves preservation of areas that contain a range of significant geological features. Geological ensembles can be viewed as a suite of inter-related sites of special scientific interest occurring in the same area. The area of the Holocene Leschenault Peninsula, a dune barrier in south-western Australia, and its leeward estuarine lagoon, described by Brocx & Semeniuk (2011a), provides an example. It contains a wide variety of geological and geomorphological features ranging from large scale to small scale, and varying in significance from International to State-wide, with many features of International significance on their own qualifying to be considered as special sites. In terms of geoconservation, addressing the various features of geoheritage value in the Leschenault Peninsula area is best achieved by viewing the system holistically as an integrated ensemble of interactive processes, geology, and geomorphology, i.e., a geopark.

One of the objectives of a geopark is to attempt to conserve ensembles of inter-related geological features over a large area. The UNESCO Geopark programme, established in 1998, for instance, defines a geopark as a territory encompassing one or more sites of scientific importance, not only for geological reasons but also by virtue of its archaeological, ecological or cultural value. Alternatively, but overlapping, the European Geoparks system, formally established in 2000 (Zouros 2000), defines a geopark as an area to conserve and valorise geological heritage through the integrated and sustainable development of their territories. Both the UNESCO Geopark programme and the European Geoparks aim to protect geodiversity, promote geological heritage and to support sustainable economic development, thus involving community and commercial interests.

In this Thesis, rather than coining a new term for large areas that contain integrated ensembles of geological features, the term ‘geopark’ is used in a modified manner from that established in Europe and UNESCO. A geopark is defined as a large scale conservation entity or an education and/or geotourism area focused on geological attributes.

Mechanisms of geoconservation can be said to have different objectives, ranging from strict preservation because of the significance of the geological feature to research and teaching, to geotourism (e.g., the Iridium-enriched layer at the K/T boundary in the Global Boundary Stratotype Section and Point Programme of the International Commission on Stratigraphy).

Given this range in scale of geological features for geoconservation, the types of areas that need to be conserved, their occurrence in isolation or within a geological ensemble, the significance of geological features varying from site to site, and the need for management ranging from strictly controlled conservation at one extreme to unmanaged tourism at the other extreme, it is proposed to classify sites of geoheritage significance into different categories of geoconservation. Geoconservation can be applied sensu stricto, from the perspective of the intrinsic importance of a geological features in that the features need to be strictly conserved, or applied sensu lato, from the perspective that geological features are noted as important and largely conserved, but there is some degree of exploitation or
utilization such as teaching or research, or applied in a situation of geotourism where geoconservation is pursued within a context of multiple land-use, education, economic development, and tourism.

In summary, sites of geoheritage significance occur at various scales, ranging from the small scale, such as geosites, and monuments, or the Sites of Special Scientific Interest (SSSI) in the United Kingdom, to the large scale involving ensembles of important geological features in geoparks and conservation areas where there are a range of inter-related geological features. They can also include reference sites, stratigraphic type sections, type fossil localities, and significant mineral or fossil localities.

This section provides a template on how to deal with various features of geological significance at various scales, in various contexts, and with variable management categories. Based on: (1) the scale or size of geological feature that is significant; (2) whether the geological feature occurs in isolation, is part of a more continuous extensive geological setting, or is part of an ensemble of features; (3) the significance of the geological feature; and (4) whether the geological feature or ensemble of geological features should be strictly conserved because of its importance, or form part of geological system for use in Science and Education, research, and geotours.

Geological features of geoheritage significance, depending on size, are allocated to the category of either geosite or geopark (without initially assigning them to International, National, or Regional significance). **Geosites** are defined as small-scale, usually < 100 m in size, with one significant geological feature (e.g., a fossil site, or a mineral site). They can occur in isolation, or require to be placed in geological context (the larger area surrounding the site is the geological context). Reference sites, stratigraphic type sections, palaeontological type localities, mineral type localities, and interesting geological localities showing fossils, stratigraphy, sedimentary structures, or contacts are examples of geosites.

Large-scale areas generally over 0.5 km in size and ranging over hundreds of kilometers in size are **geoparks**, particularly where they involve integrated geological features. They can be comprised of several different types of geological ensembles, though the important feature for their designation as geoparks is their size. Geoparks can range in characteristics as follows: 1. a large area within which is embedded a geologically significant small site < 100 m in size that needed to be placed in a geological context (the context being the larger surrounding area and, as such, the larger area is designated as a geopark); 2. a large area containing several inter-related significant small-scale geological features (e.g., fossils, stratigraphy, structures) all of which required to be placed in geological context; 3. an area showing large geological features (e.g., folds) and numerous inter-related smaller geological features and contacts; and 4. extensive (regional) sites showing large inter-related geological features (e.g., folds, structures, and gradients of metamorphism) and numerous inter-related smaller geological features and contacts.

As such, the classification proposed allocates small geological sites (with one or a few significant features), Type Sections, Type Localities, or Reference Sections to the category of geosite, and large sites with numerous inter-related features to the category of geopark.

The category of site can be further refined using descriptors such as:

“Stratigraphic Type Section”, “Pedological Reference Section”, “Mineral Type Locality”, “Palaeontological Type Locality”, or in the general case of a significant geological features such as a Pleistocene rocky shore (Semeniuk & Johnson 1985) or the best locations of the various Precambrian mylonite outcrops in South Australia (Parker 1980; Parker et al. 1988; Drexel et al. 1993) to the category of “Site of Special Scientific Interest” (using the term of the British Isles; JNCC 1996).

In terms of its significance, the category of site can be further refined using descriptors as follows: Internationally significant, Nationally significant, Regionally significant, and Locally significant.
While not necessarily related to a level of significance noted above, the site can also be described as Culturally significant, hence Internationally and Culturally significant, Nationally and Culturally significant, Regionally and Culturally significant, Locally and Culturally significant. Cultural significance can also range from International to Local.

In terms of its geoconservation level (as a management category not geoheritage significance), the category of site can be designated as:

1. high geoconservation (management) significance that may require management for protection; the zircon crystal locality of Jack Hills (Wilde et al., 2001), the Iridium layer at the K/T boundary in Gubbio, Italy (Alvarez et al. 1980; Alvarez 2009), the stromatolites of Shark Bay (Logan et al. 1974), and the Precambrian Ediacaran fauna in South Australia (Jenkins 1975; Drexel et al. 1993) stand as examples of this level of protection and management;

2. medium geoconservation (management) significance requiring moderate management for protection; the Chalk Cliffs of Beachy Head, Seaford Head, and The Seven Sisters in southern England (Gallois 1965; Melville & Freshney 1982; Mortimore et al. 2001; Larkin 2006), the Precambrian/Permian unconformity at Hallett Cove in South Australia (Cooper et al. 1972; Giesecke 1999; Drexel & Preiss 1995), and the Pleistocene rocky shore at Muderup Rocks south-western Australia (Semeniuk & Johnson 1985), and stratigraphic type sections stand as examples of this level of protection and management; medium geoconservation significance and while requiring some management for protection, can be used to teaching, education, geotours; interestingly, while Chalk Cliffs of Beachy Head, Seaford Head, The Seven Sisters, Hallett Cove, and Muderup Rocks may be Internationally significant, the management required for their geoconservation is medium grade. As such, depending on the geoconservation protection level, the sites can be used for geotours, for Science and Education, or be strictly conserved. The details of the implications of geoconservation levels, and site management are outside the scope of this Thesis.

The various categories of geosites and content within types of geoparks are diagrammatically illustrated in Figure 2.5. The geosite and geopark categories illustrated in Figure 2.5 are based on the size of the feature or features of geoheritage significance, the inter-relationship of the feature(s) of geoheritage significance, the geological context of the feature(s) of geoheritage significance and the need to conserve the geological context as well as the smaller-scale significant feature and whether there should be strict geoconservation or geoconservation with some degree of human interaction (such as geotours, education, collecting site).

Summary discussion: the scope of geoheritage in terms of categories, diversity of geology, scale, and significance

The main conclusions of this Chapter are summarised in Figure 2.6 in relation to the scope of geoheritage, in terms of its conceptual categories, the scale of geological features that need to addressed, and the levels of significance of terranes, cliffs, outcrops and crystals that need to be applied.

As noted above, the four categories of sites of geoheritage significance are very different in their scope. The first involves type examples, or reference sites or locations, and these were some of the first recorded and preserved sites of geoheritage significance, and addressed type stratigraphic and soil locations, type fossil locations, and geomorphic locations as standards for Earth scientists for research and education. Culturally significant sites were those where geological principles were first explored and explained – Hutton's unconformity site is a typical and classic example. Geohistorical sites are those where former Earth processes and Earth history can be inferred and reconstructed from outcrops such as cliffs - the Grand Canyon serves as an example of this category in that it exhibits a classic stratigraphic sequence and geomorphology to enable reconstruction of Earth history. The last category relates to modern landscapes where actives processes are operating – these provide information about extant Earth processes per se, and also are useful for interpreting ancient sequences.
The scale of a site of geoheritage significance illustrated in Figure 2.6 from Brocx (2008) intends to convey the notion that the importance of a geological feature may be at the terrane scale (in this diagrammatic example, an illustration of a large scale igneous intrusion, and its metamorphic aureole as the principle of a large scale feature) is used, but can range down to the cliff, bedding or rock scale, and ultimately to the crystal aggregate and individual crystal. These matters are important because the full gamut of scale in geoconservation, to date, has not been systematically addressed, as in many geological reconstructions of Earth history the analysis may begin at the crystal scale (cf. Logan 1974; Hobbs et al 1976; Barker 1998), but also can encompass larger frames of reference (using structural and metamorphic examples for the concept of the employment of increasing scale, see Turner & Weiss 1963, Hobbs et al 1976; Wilson 1982; Nicholas 1987; Davis & Reynolds 1996; and Barker 1998).

Finally, regardless of the size of the geological phenomenon being considered, be it terrane-scale, outcrop or bed scale, or crystal scale, the significance of the geological feature whether it is international, national, State/regional, or local in importance needs rigorous criteria for assessment. This aspect applies equally to features of geology such as igneous, metamorphic, sedimentary, or structural terranes and their crystals, as well as to geomorphic features such as distinct mountain ranges, smaller scale mesas and buttes, down to variable microtopographic features on, say, a salt-weathered rocky shores cut into specific rock types.
Chapter 3: Methods

A variety of methods were used in this study. These are described below as follows:

1. Literature review of coastal systems
2. Literature review of globally-significant coastal systems
3. Literature review of significant coastal systems in Western Australia and Australia
4. Literature review of Western Australian geology, and geological map analysis
5. Topographic map, satellite imagery, and aerial photograph analysis
6. Field studies to selected areas to examine selected Western Australian coasts
7. Literature review of international and national geoheritage conservation policies
8. Literature review of history of geoconservation in Australia and the development of geoheritage policies
9. Literature review of history of geoconservation in Western Australia and the development of geoheritage policies.

The methods outlined in this Chapter fall into three broad categories, namely: (1) literature reviews (using books, peer reviewed Journal papers, the Australian National Archive, and internet searches,) of global and Australian coastal systems, coastal geology, climate, and oceanography, of the terms and concepts for description of igneous rocks, metamorphic rocks, sedimentary rocks, structural geology, and sedimentary-structures, and of geoconservation and policy; (2) field studies and site descriptions of area(s) based information from the literature reviews, and using the scalar method of description illustrated in Figure 3.1 (from Semeniuk et al. 2011); and (3) designing the Geoheritage Tool-kit.

The Geoheritage Tool-kit was developed wholly within this study and not derived from the literature or modified from other already existing methods. It is a philosophy of approach, or tool-kit, to identify, categorise, and evaluate sites of geoheritage significance. The Geoheritage Tool-kit is described and developed in Chapter 7.

Location of the various sites mentioned in this Thesis globally, in Australia, and in Western Australia are shown in Figures 3.2-3.7. While the focus on site visits and developing the coastal classification was overwhelmingly centred on Western Australia as listed below (Figures 3.4-3.6), other areas along coastal Australia were opportunistically visited and assessed in relation to the classification of coastal types being developed in this Thesis (Figure 3.7); these latter sites are: Buffalo Creek, Lee Point, Casuarina Reserve, Rapid Creek, and Port Darwin in the Northern Territory; Weipa, Cairns, 1770, Gladstone, Bundaberg, and Brisbane in Queensland; Newcastle, Long Reef, Sydney cliffs, Wollongong, Kiama, Ulladulla, Bermagui, and Merimbula in New South Wales; Ceduna, Port Neill, Tumby Bay, Port Lincoln, Hallett Cove, The Coorong, and Kangaroo Island in South Australia; and the north coast of Tasmania between Wynyard and Tomahawk.

Literature review of coastal systems

Literature dealing with coastal systems was reviewed to provide a framework for this study. This literature involved general texts describing coastal types and coastal processes around the world, more specific books and papers on region-specific coastal areas such as Shark Bay, the Persian Gulf, the Great Barrier Reef, estuaries and deltas to provide geographically distinct processes and products, and text books and general principle and conceptual papers on the relationship of coastal process to coastal landforms and sedimentation style. This literature included: Alexander et al (1998); Bates & Jackson (1987); Bathurst (1975); Bird & Schwartz (1985); Davies (1980); Davis (1978, 1994); Emery & Kuhn (1982); Finkl (2004); Ginsburg (1975); Inman & Nordstrom (1971); Logan (1970, 1974); Holmes (1966); Scholle et al (1983); Johnson (1919); Kelletat (1995); King (1972); Komar (1998); Le Blanc (1976); Morgan (1970); Purser (1973); Reineck & Singh (1980); Schwartz (1973, 2005); Shepard (1973); Snead (1982); Trenhaile (1980, 1987, 1997); Woodroffe (2002). The more detailed papers dealing with specific processes and products along the coast in Australia and globally, and the more specific site descriptions relating to Australia and Western Australia, are referenced where appropriate in the ensuing text in this Thesis.
Literature review of globally-significant coastal systems

Literature dealing with coastal systems that have been recognised globally as being of geoheritage significance was reviewed to provide a background to the development in this study of coastal classification, and criteria for geoconservation. This included literature on a range of coastal and near-coastal (barrier) localities (the latter including near-shore keys, islands, and barriers), that have already been globally recognised as World Heritage sites, Ramsar sites, and National Parks. The areas researched in the literature and their relevant supporting references are listed in Table 3.1 below and the locations are shown in Figure 3.3. More general and summarised descriptions of these areas also have been derived from appropriate Chapters in Bird & Schwartz (1985).

Badman (2010) provides a review of World Heritage Sites (including coastal areas) from the perspective of their geomorphological values, and the bases for their selection using IUCN criteria of “Outstanding Universal Values”. Most of the World Heritage sites listed in Badman (2010) have been reviewed as part of the investigation into globally-significant coastal systems noted in Table 3.1 below. Review of Badman (2010) will be carried out in more detail in the Chapters on Policy.

Table 3.1: Locations of globally recognised coastal areas and the supporting literature

<table>
<thead>
<tr>
<th>Location</th>
<th>Literature</th>
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<tbody>
<tr>
<td>Shark Bay in Western Australia</td>
<td>Logan (1970, 1974)</td>
</tr>
<tr>
<td>Fraser Island in eastern Australia</td>
<td>Boyd et al. (2004a, 2004b, 2008), Price (2013)</td>
</tr>
<tr>
<td>Bay of Mont Saint Michel</td>
<td>Larsonneur (1975), Tessier (1993)</td>
</tr>
<tr>
<td>Gulf of California</td>
<td>Thompson (1968)</td>
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</table>
In addition to these specific sites listed in Table 3.1, the coastline of Great Britain is considered to be not only extremely varied and dynamic, but also a great national asset, valued for its natural heritage and scenic beauty (May & Hansom 2003). This will be discussed in the section on international reviews in Chapter 10.

**Literature review of significant coastal systems in Australia and Western Australia**

Since the development of classification of coastal types and criteria for assessing significance of geoheritage sites and criteria for geoconservation was a critical part of this study, literature dealing with Australian coasts and coastal classifications were accessed. In particular, there was a focus on literature dealing with Australian coasts that integrated coastal forms, geoconservation, and criteria for assessment of significance. The Tasmanian Coast (Kiernan 1990, 1997; Dixon, G 1996; Corbett et al. 2014), the Victorian Coast (Joyce & King 1980; White et al. 2003) and the Western Australian coast (Semeniuk & C A Semeniuk 2001, Brocx & Semeniuk 2011a, 2011b), Semeniuk & Brocx (2011), and Semeniuk et al. (2011) are examples of these.

**Literature review of Western Australian geology, and geological map analysis**

Bedrock, basement, and pre-Holocene geology is an important determinant of coastal form and development of coastal types and, as such, a review was undertaken of the geology of Australia as it is expressed at the coast. This involved examining geology maps at scales of 1:1 000 000 and 1:250 000. Coastal forms were related to geological provinces and basins, geological structure (i.e., where the geological grain of hinterland geology in terms of the occurrence of major lithological suites, and folds, strike, and trends influenced coastal forms). Thus coast types developed in this Thesis were placed into a framework of geological provinces and basins. Together with climate and oceanographic setting, this review of geology, as expressed at the coast, provided the basis to the coastal classification of the Western Australian coast.

Geological maps and accompanying handbooks, and geological literature pertaining to Western Australian geology used in this study include: Cambridge Gulf area, North-east Kimberley, Northern Kimberley, North-west Kimberley, the King Sound area, Dampier Peninsula, the Canning Coast, the Pilbara Coast, Cape Range, the Gascoyne River Delta region, Shark Bay region, Red Bluff and the Murchison River estuary, Kalbarri, Dongara coast, Perth Metropolitan rocky coast, focused on Muderup Rocks, North Beach, Ocean Reef, Point Peron, Becher Point, Yalgorup National Park, focused on Preston Beach, Leschenault Peninsula and its leeward estuary, South Bunbury coast and Geographe Bay, Bunker Bay area, the Leeuwin Coast between Cape Naturaliste and Cape Leeuwin, the southern Coast (including Black Point, Bunker Inlet, Conspicuous Cliffs, Walpole-Nornalup Inlet, the Denmark coast, focused on the rocky shores and Irwin Inlet, the Albany coast focused on rocky shores, tidal flats, Lake Sepping, and tombolos), Bremer Bay region, The Esperance coast, Bilbunya Dunes region, Eucla coast, and the Eyre coast.

**Topographic map, satellite imagery, and aerial photograph analysis**

The following maps and images were analysed in terms of coastal forms and coastal features to develop the coastal classification and the hierarchical approach to coastal categorization: topographic maps at scales of 1:1 000 000, 1:250 000 and 1:100 000, geological maps at scales of 1:250 000, satellite images at scales of 1:250 000 to 1:10 000, and aerial photographs at scales of 1:40 000 to 1:10 000. Topographic maps at scales of 1:250 000, and 1:100 000, and satellite images at scales of 1: 40 000 to 1:10 000 also were used for the more detailed studies in selected areas. The various topographic and geologic maps used in this study are listed in Table 3.2.

Google™Earth (a virtual globe, map and geographical information program available via the Internet; Google™Earth 2005-2007 - http://www.google.com/ enterprise/mapsearth/ products/earthpro.html) also was used to study the geometry, configuration, and landforms along coastal Western Australia, and to study the selected areas. Google™Earth was used at various scales depending on the detail required, and could be used to study the coastline three-dimensionally in vertical and in oblique ‘aerial’ views.
Table 3.2: Maps used for Western Australian coastal geomorphology, coastal forms, and coastal geology (letters and/or numbers after each map name refer to the number of specific maps). Map sheets are ordered north to south, and then west to east.

<table>
<thead>
<tr>
<th>1:1 000 000 topographic maps</th>
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<tr>
<td>Darwin SD52; Brunswick Bay SD51; Rowley Shoals SE50; Broome SE51; Cloates SF49; Hamersley Range SF50; Carnarvon SG49; Meekatharra SG50; Perth SH50; Albany SI50; Esperance SI51; Nullarbor Plain SH52.</td>
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<th>1:250 000 topographic maps</th>
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<tr>
<td>Londonderry 5; Montague Sound Special; Drysdale 9; Medusa Banks 10; Camden Sound Special 15; Prince Regent 16; Cambridge Gulf 14; Pender 2; Yampi 3; Charnley 4; Broome 6; Derby 7; Lagrange 10; Mandora 13; Port Hedland Special 4; Dampier Special 2; Roebourne 3; Onslow 5; Yarraloola 6; Minilya Special 16; Yanrey Special 9; Carnarvon Special 4; Wooramel 5; Monkey Special 12; Yaringa 9; Ajana 13; Geraldton Special 1; Dongara 5; Hill River 9; Perth Special 14; Pinjarra 2; Collie 6; Busselton Special 5; Pemberton Special 10; Mount Barker Special 11; Many Peaks Special 2528; Bremer Bay 12; Ravensthorpe 5; Esperance Special 6; Malcolm Special 7; Culver 4; Madura Special 13; Eucla Special 14.</td>
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<th>1:250 000 geological maps</th>
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<tbody>
<tr>
<td>Medusa Banks (Sheet SD 52-10); Drysdale-Londonderry (Sheet SD 52-9.5); Montague Sound (Sheet SD 15-12); Prince Regent-Camden Sound (Sheet SD 51-16 &amp; 15); Yampi (Sheet SE 51-3); Pender (Sheet SE 51-2); Broome (Sheet SE 51-6); Langrange (Sheet SE 51-10); Mandora (Sheet SE 51-13); Port Hedland/Bedout Island (Sheet SF 50-04 and part Sheet SE 50-16); Roebourne (SF 50-03); Dampier, Barrow Island (Sheet SF 50-01, SF 50-02); Yarraloola (Sheet SF 50-06); Onslow (Sheet SF 50-05, SF 49-08); Yanrey, Ningaloo (Sheet SF 49-12, SF 50-09); Winning Pool, Minilya (Sheet SF 50-13 and part of Sheet SF 49-16); Quobba (Sheet SG 49-04); Shark Bay, Edel (Sheet SG 49-08, SG 49-12); Wooramel (Sheet SG 50-05); Yaringa (Sheet SG 50-09); Ajana (Sheet SG 50-13); Geraldton, Houtman Abrolhos (Sheet SH 49-04, SH 50-01); Dongara, Hill River (Sheet SH 50-05, SH 50-09); Perth (Sheet SH 50-14); Pinjarra (Sheet SI 50-02); Collie (Sheet SG 50-04); Busselton, Augusta (Sheet SI 55-05, SI 50-09); Pemberton, Irwin Inlet (Sheet SI 50-10, SI 50-14); Mount Barker, Albany (Sheet SI 50-11, SI 50-15); Bremer Bay (Sheet SI 50-12); Ravensthorpe (Sheet SI 51-05); Esperance, Mondrain Island (Sheet SI 51-06, SI 51-10; Malcolm, Cape Arid (Sheet SI 51-07, SI 51-11); Culver (Sheet SI 51-04); Madura, Burnabdie (Sheet SH 52-13, SI 52-01); Eucla, Noonaera (Sheet SH 52-14, SI 52-02).</td>
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</tbody>
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<table>
<thead>
<tr>
<th>1:100 000 topographic maps</th>
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<tbody>
<tr>
<td>Troughton 4170; Londonderry 4271; Rulhieres; Admiralty Gulf 4069; Van Sittart 4169; Drysdale 4269; King George 4369; Casuarina 4469; Bigge 3968; Warrender 4068; Berkeley 4468; Medusa 4568; Knob Peak 4668; Chapman Bay 3767; Brunswick 3867; Prince Frederick 3967; Wyndham 4567; Cockell 3766; Methuen 3866; Leasepe 3465; Sunday Island 3565; Yampi 3665; Collier Bay 3865; Walcott 3865; Lacepede 3364; Pender 3464; Cornabie 3564; Kimbolton 3664; Carrot 3363; Fraser 3563; Derby 3663; Broome 3362; Gourdon Bay 3261; Vlare 3361; Lagrange 3260; Anna Plains 3159; Phire 3259; Poissonnier 2758; Keraudren 2858; Shoonta 2958; Mandora 3058; Radi 3158; Cossigny 2457; Thouin 2557; Port Hedland 2657; Preston 2156; Dampier 2256; Roebourne 2356; Sherlock 2456; Airlie 1955; Mardie 2055; Jurabie 1654; Exmouth 1754; Tubridgi 1854; Onslow 1954; Cape Range 1653; Learmonth 1753; Talandji 1853; Point Coates 1652; Mauds Landing 1651; Monument 1550; Minilya 1650; Quobba 1549; Bernier 1548; Carnarvon 1648; Greenough 1647; Quin 1446; Denham 1546; Shark Bay 1646; Wooramel 1746; Edel 1545; Peron 1645; Hamelin 1745; Pepper 1544; Tamala 1644; Zuytdorp 1643; Coolcarda 1743; Kalbarri 1742; Hutt 1741; Northampton 1841; Geraldton 1840; Dongara 1839; Beagle Islands 1838; Arrowsmith 1938; Jurien 1937; Wedge Island 1936; Ledge Point 1935; Gingin 2035; Perth 2034; Fremantle 2033; Pinjarra 2032; Bunbury 3021; Busselton 1930; Leeuwin 1929; Donnelly 2029; Meerup 2028; Northcliffe 2128; Deep River 2228; Rame Head 2227; Denmark 2328; Parry Inlet 2327; Albany 2427; Many Peaks 2528; Pallinup 2629; Cheyne 2628; Bremer 2729; Hood Point 2829; Ravensthorpe 2930; Oldfield 3030; Stokes Inlet 3130; Esperance 3230; Merivale 3330; Mondrain 3329; Howick 3430; Sandy bight 3530; Malcolm 3630; Wattle Camp 3731; Culver 3832; Rockhole 3932; Cardanumbi 4033; Dover 4032; Burnabbie 4133; Scorpion bight 4233; Middini 4333; Red Rocks Point 4438; Archdeacon 4533; Eucla 4634.</td>
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Field studies in selected areas to examine selected Western Australian coasts

To investigate the coasts in Western Australia in order to document their variability with respect to geological, climatic, and oceanographic setting, and to obtain information at smaller scales on coastal features (i.e., to construct an inventory of geological features for a given locality), fieldwork was undertaken to numerous localities along the length of the Western Australian coast. These site visits were undertaken in selected areas to document coastal form and describe the geological features at the various scales of their development (construct an inventory of geoheritage features). Forty four areas were selected to capture the full variety of coastal types in a range of geological settings. The bases for the selection of sites were: a minimum of at least five sites from each of Western Australia’s major geological regions; enough sites selected to capture the full climatic, and oceanographic settings of coastal Western Australia (from tropical to near-temperate; from arid to humid; from wave-dominated, tide-dominated, to wind-dominated); selection of sites from igneous rock provinces, sedimentary rock provinces, metamorphic/structural rock provinces; and from craton regions to sedimentary basin regions; and sites selected from depositional coasts to erosional coasts. The areas are (Figure 3.5):

1. Cambridge Gulf
2. Kimberley Coast
3. King Sound
4. Willie Creek
5. Broome region coast, focused on Gantheaume Point and Entrance Point at Broome, Dampier Creek, Black Rocks
6. Roebuck Bay and Roebuck Plains
7. Barn Hill coast
8. Eighty Mile Beach
9. Pilbara Coast focused on Finucane Island at Port Hedland
10. Pilbara Coast focused on Cossack
11. Pilbara Coast focused on the Point Samson
12. Pilbara Coast focused on Cleaverville
13. Pilbara Coast focused on Hearson Cove
14. Pilbara Coast focused on Dampier Archipelago
15. Pilbara Coast focused on King Bay
16. Pilbara Coast focused on Maitland River Delta
17. Pilbara Coast focused on Onslow
18. Cape Range (Exmouth region)
19. Gascoyne River Delta
20. Shark Bay region
21. Murchison River estuary, Kalbarri
22. Kalbarri: Red Bluff
23. Point Leander, Dongara coast
24. Perth Metropolitan rocky coast, focused on Muderup Rocks, North Beach, Ocean Reef
25. Point Peron
26. Becher Point
27. Yalgorup National Park, focused on Preston Beach
28. Leschenault Peninsula and its leeward estuary
29. South Bunbury coast
30. Geographe Bay
31. Bunker Bay
32. Leeuwin Coast between Cape Naturaliste and Cape Leeuwin
33. D’Entrecasteaux coast
34. Black Point
35. Broke Inlet
36. Conspicuous Cliffs
37. Walpole-Nornalup Inlet
38. Denmark coast, focused on the rocky shores and Irwin Inlet
39. Albany coast focused on rocky shores, tidal flats, Lake Seppings, and tombolos
40. Bremer Bay
41. Esperance coast
42. Bilbunya Dunes region
43. Baxter Cliffs
44. Eyre Coast

At each site, the geology was described in a scalar manner using the approach illustrated in Figure 3.1 (from Figure 1.3 in Semeniuk et al. 2011). Established terms for description of igneous rocks, metamorphic rocks, sedimentary rocks, structural geology, and sedimentary-structures have been obtained and applied from the works cited above in ‘Literature review of coastal systems’ and ‘Literature review of globally-significant systems’. Other site-specific methods used on-site for compiling detailed inventory of geological features at various scales at these localities as developed during this study are more appropriately outlined in the section dealing with the Geoheritage Tool-kit.
Literature review of international and national geoheritage conservation policies

Literature dealing with international and national geoheritage conservation policies was accessed to provide a background to the manner in which geoconservation of sites of geoheritage significance was dealt with. This review showed that while there was literature on geoheritage, geoconservation, and policies, there was little direct literature on coastal geoheritage and its geoconservation as defined in this Thesis.

Literature review of history of geoconservation in Federal Australia and the development of geoheritage policies

Similarly, a literature review was undertaken of the history of geoconservation federally in Australia and the development of geoheritage policies to provide a background to the manner in which geoconservation of sites of geoheritage significance was dealt with. Again, this review showed that there was little literature on coastal geoconservation and policies but only generally on matters of geoheritage and geoconservation.

Literature review of history of geoconservation in Western Australia and the development of geoheritage policies

A literature review was undertaken of the history of geoconservation in Western Australia and the development of geoheritage policies to provide a background to the manner in which geoconservation of sites of geoheritage significance was dealt with. This review showed that there was little literature on coastal geoconservation and policies but only generally on matters of geoheritage and geoconservation.

Selection of areas for case studies for applying the Geoheritage Tool-kit

The scope of this Thesis meant that there was a limit to the number of case studies that could be selected. Based on the discussion presented in the section “Scale and categories of sites of geoheritage significance from geosites to geoparks”, case studies of the application of the Geoheritage Tool-kit were needed to be drawn from large-scale areas that could be designated as geoparks and from small-scale areas that could be designated as geosites. Four large-scale areas at the size of geoparks and four smaller scale areas at the size of geosites were used to test the application of the Geoheritage Tool-kit. Major factors in the selection of the areas as case studies for both the geoparks and geosites were accessibility, excellent exposures, diversity of geological features therein, contribution they would make to the geological knowledge, and (if possible) reasonably well-described in the literature.

The four large-scale areas were (1) the Kimberley Coast, (2) King Sound and the Fitzroy River delta, (3) the Leschenault Peninsula and Leschenault Inlet estuary, and (4) the Walpole-Nornalup Inlet Estuary. The small-scale site-specific case studies were located at (1) Willie Creek, north of Broome, (2) Entrance Point at Broome, (3) Point Leander at Dongara, and (4) Muderup Rocks, south of Cottesloe.

The rationale for selecting the four geoparks was that they are contrasting coasts located in tropical humid, tropical semi-arid, subtropical subhumid, and near-temperate humid climates, and ranging from extensive and impressive coastal ria systems (the Kimberley Coast) to the world’s largest macrotidal delta (the Fitzroy River delta in King Sound) to Western Australia’s unique and complex dune barrier and leeward lagoon (Leschenault Peninsula and Leschenault Inlet estuary) to a unique twin ria estuary in Western Australia’s heartland of National Parks (the Walpole-Nornalup Inlet Estuary). This provided a wide diversity of coastal types and setting with which to apply and test the Geoheritage Tool-kit.

The rationale for selecting the four geosites was that three are well-exposed, readily-accessible and geologically interesting exposures occurring as sea-cliffs cut into Quaternary limestones, viz., Willie Creek, Point Leander, and Muderup Rocks, and so provide comparative and contrasting stratigraphic sections for assessing geoheritage values. Willie Creek provides mid-Holocene tidal sand to beach to dune stratigraphy in a macrotidal tropical setting; in contrast, Point Leander provides a Pleistocene coral reef stratigraphy; Muderup Rocks provides a Pleistocene rocky shore to beach-to-dune stratigraphy. The outcrops represent the best of their kind in the region, and each is turn exhibits a
diversity of geological features for use in geoheritage evaluation. Entrance Point was selected because it provides a well-exposed, readily-accessible and geologically interesting exposure of Mesozoic sandstone stratigraphy with an abundance and diversity of sedimentary structures.

Each of these areas was researched through literature surveys, and fieldwork to obtain an extensive information base for use in applying the Geoheritage Tool-kit.
Chapter 4: Why the coastal zone is a special environment -
coastal geoheritage encompassing physical, chemical, and biological processes,
landforms, and other geological features in the coastal zone

The coast is one of the most complex environments on the Earth’s surface, being a zone of intersection and interaction of land, sea, groundwater, and atmosphere and the processes therein, and carries a multiplicity of processes and products at a number of scales that are either not present or only weakly developed elsewhere. While features such as lithology, structure, or geological framework that contribute to geodiversity at the coast also occur in other Earth environments, in addition to prevailing or ubiquitous geological features, the coastal zone is one that generally results in greater geodiversity (i.e., varied assemblage of geological features) than elsewhere. As with other environments, the complexity and geodiversity developed along the coast are variable according to parent rock types, sediments, and other materials, biodiversity, hydrochemical effects, diagenesis, and variable according to environmental setting and climate.

As determined in Chapter 3 from the literature listed in the reviews of general coastal systems and globally-significant coastal systems, and summarised by Brocx & Semeniuk (2009a), there is large range of interacting physical, chemical and biological processes in the coastal zone; these include: waves, tides, storms, and cyclonic activity (all resulting in erosion, sediment mobility, particle-size sorting, sedimentary structures); development of a splash zone; onshore winds resulting in shore-directed wind waves and longshore drift, and in erosion, transport, particle sorting, lag deposits, and dune building; sedimentation mediated physically by fluvial influx, longshore and/or onshore transport, and tidal currents, or biologically by skeletal production; bioerosion; chemical erosion; salt weathering; tidal invasion of coastal sedimentary bodies by seawater; evaporation and transpiration; hydrochemical effects such as solution, or precipitation of carbonates, gypsum, or halite; fresh-water seepage and its effect on ecology and coastal erosion; sediment delivery fluvially; and biological effects including skeletal production, encrustation, biostromes and bioherms, grain fragmentation, and bioturbation.

A significant factor also is the prevailing nature of many of the processes therein. Coasts commonly exhibit shore-normal environmental gradients and hence a graded expression of processes, resulting in variation in complexity and geodiversity in physical, geochemical and biological products across the shore, and variation in fine- to small-scale stratigraphic sequences. To provide a perspective of the expression of any geodiversity of bedrock, and of the diversity and complexity of sedimentary systems in the coastal zone, selected coastal zones are compared with terrestrial environments for specific rock types, and specific sedimentary sequences. While there is overlap, coastal environments present greater complexity and geodiversity of physical, chemical and biological products. Because they interface with oceans, coastal deposits and coastal forms also can record a history of sea level, climate, and oceanic processes. It is the range and assemblages of distinctive sedimentological and erosional features, expressed geomorphologically and stratigraphically along the coast, and their strength of development, that sets coastal geoheritage apart from continental (or inland) geoheritage.

This Chapter explores the various features of geology (and geomorphology as a subset of geology), expressed as geodiversity in the coastal zone as a prelude to identifying coastal types and sites that may have geoheritage significance (to be developed in later Chapters). Under the umbrella term, coastal geoheritage, this Chapter explores the reasons for coastal geodiversity, i.e., the physical, chemical, and biological processes, landforms, and other geological features that occur in the coastal zone, and formally recognises that coastal geodiversity and coastal geoheritage are especially significant in a context of geoconservation.

To place the complexity of the coastal zone in perspective, and hence the geodiversity of the coastal zone into perspective, rocks and sediments in the coastal zone are compared with those in terrestrial environments, e.g., a Pleistocene calcarenite exposed at a rocky shore with that exposed in an inland cliff, and an accreting upward-fining sequence of tidal flat sediment with that of a point bar, amongst other examples.
The term ‘bedrock’ is used in this Chapter to refer to indurated rocks of sedimentary, igneous, and metamorphic origin, of Precambrian to Phanerozoic age not only to Precambrian basement rocks. In this Thesis, for instance, the Ordovician Tumblagoooda Sandstone of Opik (1959) at Red Bluff, Kalbarri (Cockbain et al. 1975; Hocking et al. 1987; Hocking 1991, 2000), and the Mesozoic Broome Sandstone at Broome (Brunnschweiler 1954, 1957; Veevers & Wells 1961; Cockbain et al. 1975) are treated as ‘bedrock’ to coastal sediments and coastal processes.

**Definition of coast and coastal, and other terms**

The term “coast” and its derivatives are reviewed and then defined here because the ideas of geoheritage and geoconservation will be applied to this very specific site of the Earth’s environment.

Few texts define the term *coast*. Even encyclopaedia devoted to geomorphology (Fairbridge 1968), or to beaches and coastal environments (Schwartz 1982) do not address its definition, but rather focus on using its derivative as an adjectival descriptor, *e.g.*, *coastal* classification, *coastal* ecology, *coastal* erosion, and so on. A brief review of those texts dealing with coastal systems where the definition of *coast* is somewhat addressed (although not to any depth) is presented below.

Reineck & Singh (1980) use the term *coast* as the zone that separates continents from the sea. Davis (1978) defines a *coastal area* as the zone where land and sea meet, where there can be a variety of complex environments. Bates & Jackson (1987) define *coast* as the strip of land of indefinite width that extends from the low tide line inland to the first major change in landform feature. Woodroffe (2002) defines *coast* as the interface between land and sea. Rather than using the term *coast*, Haslett (2009) following Carter (1988) uses the term *coastal zone* as the area between the landward limit of marine influences and the seaward limit of terrestrial influence. Haslett (2009) also separates definition of a coast as used by scientists from that used for planning and management (*e.g.*, as defined by Kay & Alder 2005).

In all definitions, generally, the term *coast* is applied to shoreline environments, usually for the strip of land that is located between high and low tide. Some authors extend the use of the term to environments in the nearshore breaker zone and to the nearshore supratidal zone. In Western Australia, for planning purposes, the *coast* is defined to include the coastal waters to a depth of 30 m, as well as reefs, estuaries, tidal rivers and land which is presently subjected to coastal processes (such as mobile dunes, areas inundated by storm surge, and vegetated foreshore areas exposed to onshore winds). In addition, the *coast* includes a fringe of stable land suitable for coast-related activities (Anon 1993).

The descriptor *coastal* is more general as a term, and has a broader scope in that it includes the *coast* itself and the adjoining area in the marine environment and terrestrial environment that are proximal to the coast, sometimes merely proximal geographically, but other times with an environmental inter-relationship implied (*e.g.*, deposits stranded inland by progradation, but having been formed by earlier coastal sedimentation; or within the reach of wave splash or salt spray). For instance, *coastal* is defined by Bates & Jackson (1987) as pertaining to a coast, bordering a coast, or located at or near a coast, and *coastal area* as the area of land and sea bordering a shoreline. However, there is general disagreement on how far inland and how far seaward constitutes *coastal* (Anon 1995a, 1995b).

While *coast* as a term may be more or less defined in the scientific literature, in the area of coastal planning policy for administrative purposes, *coastal* is less precise, with different definitions generated by coastal managers in the various local governments based on administrative boundaries created for a specific demographic coastal location and the issues being addressed (Anon 1995a, 1995b). Here, *coastal*, depending on author, may be narrowly defined, or so broad as to encompass a wide variety of Holocene shoreline, Holocene near-shoreline, prograded Holocene shoreline complexes (such as beach-ridge plains, *cf.* Searle et al. 1988; or prograded tidal flats *cf.* Semeniuk 1981a, 1981b, 1982), and former Quaternary shoreline landforms. In the Standing Committee on Environment, Recreation and the Arts, in a report titled *The Injured Coastline: Protection of the Coastal Environment* to the Australian House of Representatives, it was argued that there were three main approaches to defining a coastal zone (Anon 1991b), these being: 1. administrative (based, for instance, on administrative boundaries or offshore legislative boundaries, and clearly not scientific); 2.
linear (based on arbitrary boundaries such as a linear reference point, and therefore mostly cadastral); and 3. biophysical (based on physical features such as a mountain range, or a natural ecosystem, and not necessarily related to the coastal zone but to other conspicuous boundaries or features). These approaches are conceptually and scientifically flawed.

In this Thesis, the term coast will be used to denote the modern strip separating land and sea, generally occurring between high and low tide, and the term coastal will be used to denote a variety of environments that relate to the interaction between oceanic and terrestrial processes. As such, these will contain both land and ocean components, and have boundaries to the land and ocean that are determined by the degree of influence of the land on the ocean and the ocean on the land; and may not be of uniform width, height, or depth (Kay & Alder 1999, 2005). These environments may include, for example, the seaward margin of prograded coastal plains, or coastal dune belts (where they have been formed by coastal processes), or areas influenced by marine processes such as salt spray. The notion of ‘coast’ as a boundary between environments with marine processes and those where terrestrial processes dominate is encapsulated in Figure 2.4. There will be geomorphic, sedimentary, hydrologic, hydrochemical, and biological expression across this boundary. The example in Figure 2.4 illustrates one extreme of a coast where the boundary is gradational. At the other extreme where the coast is comprised of a sea cliff, the boundary will be relatively sharp geomorphically, but more diffuse and overlapping (though still over a relatively narrow zone) hydrologically because of splash and sea spray, hydrochemically because of differential response of different host rocks to phreatic seawater, splash, and sea spray, and biologically because biota will respond to the overlapping and decreasing gradational effects of immersion, splash, and spray on different types of host rocks.

In this context, the term coastal geoheritage is used to denote geoheritage aspects of the coastal zone, where the coastal zone is the shore, and where terrestrial and oceanic areas are, or have been, influenced by coastal processes.

As noted above, sites of geoheritage significance can include features that range in size from crystals to geological features at the scale of mountains and landscapes (Figure 2 of Brocx & Semeniuk 2007 and Figure 2.2 herein). This size gradation and processes/products at various scales also occur in the coastal zone, with geomorphic features ranging from micro-pinnacles (lapiés) and tafoni, to specific types of cliffs, to large coastal (depositional) systems such as deltas. Scale is formally addressed in terms of frames of reference of fixed sizes (Chapter 2), using regional, large, medium, small, and fine scales (after Semeniuk 1986a), or megascale, macroscale, mesoscale, microscale, and leptoscale (after C.A. Semeniuk 1987). That is, the frame of reference is used to denote those features evident at that particular scale. For instance, cross-lamination, sedimentary layering, lamination, bubble sand, shell layers, tafoni, micro-pinnacles (lapiés), etched surfaces, and smoothed surfaces are evident within a 1 m x 1 m frame of reference, while larger cliff faces, shoreline benches and sandy spits are evident within a 10 m x 10 m or 100 m x 100 m frame of reference.

Since coasts are Holocene, the emphasis on coastal geoheritage features is on Holocene forms, whether they are marine inundation features (formed by the last post-glacial transgression), erosional features cut into materials of Holocene, Pleistocene, or older age, or depositional landforms and sedimentary sequences developed during the Holocene. As such, Pleistocene coastal landforms, Pleistocene coastal sedimentary sequences, and other Pleistocene features (regardless of how closely they are related spatially to Holocene shorelines), and exhumed pre-Holocene former coastlines (such as exhumed cliffs or rocky shore pavements), are relegated to the category of ancient sequences. Stranded sea cliffs of Pleistocene age or earlier are not included in this definition of coast.

The rationale for excluding Pleistocene sea cliffs is that they are former not modern coasts. In extreme cases, they can be former coasts stranded up to several kilometres inland, even tens of kilometres inland (cf. Belperio 1995 for stranded limestone shorelines of The Coorong hinterland and, at Shark Bay, Tertiary limestone mesas as stranded former sea cliffs, stacks, and small near-shore islands – cf. Figure 5 of Logan et al. 1970). All rock types from Precambrian to Pleistocene in age can be former sea cliffs, and in the modern environment can influence current patterns and can contribute sediment directly to the coast, but this does not make the cliffs themselves modern coasts. The definition of coast in this Thesis is fairly broad (encompassing the zone of wave action, tides, splash and salt spray) and specifically focuses on use of the term to denote modern coasts with modern ongoing processes.
How is the coastal zone different from other environments?
As a dynamic zone of intersection and interaction of land, sea, groundwater, and atmosphere, the coastal zone carries with it an abundance of processes and products that are not present in other environments or only weakly developed in those other environments. For instance, in contrast to the shore environment, nearby marine environments, though graded with respect to depth (with its attendant effects on wave energy intersecting the shelf floor, sediments, and biota), tend to be more homogeneous environmentally because the oceanic milieu itself tends to be relatively more uniform, and generally removed from processes such as wind, or fresh-water discharge (Kuenen 1950; Shepard 1973; Berger 1974; Ginsburg & James 1974; Swift 1974; Wilson & Jordan 1983; Swift et al. 1984; Collins 1988). Therefore, the complexities of shore processes and products generally are absent in the adjoining shelf environment. The shelf may be underlain by a relatively uniform sheet of sediment (or rock), while the adjoining coast will comprise a range of sediments (or morphologic types cut into rock) that reflect the gradient of the effects of waves, tides, wind, and hydrochemistry that impinge on or interact with the shore.

This is not to imply that terrestrial environments cannot also be complex, but their geological complexity generally is manifest in two ways: firstly, in the inherent structural, lithological and mineralogic variability in the underlying materials (though their expression as parent material is often diminished by weathering); and secondly, in any weathering itself which produces soils that reflect hydrochemical and geochemical processes acting on these materials. In fact, soils and palaeosols, resulting from hydrochemical interactions on various parent rocks, can present some of the most complex structural and geochemical products in the terrestrial environment (Hunt 1972; Buol et al. 1973; Arnold 1983; FitzPatrick 1983; Leeper & Uren 1993), particularly since the processes may have been operating over millennia; this has already been recognised elsewhere (Gauld et al. 2003). While soils can express complexity in the terrestrial environment, the geodiversity (if developed) is usually at the geochemical level and in terms of pedogenic structures. However, soils generally do not exhibit the range and scale of features that can be developed at the coast.

Leaving aside soils, the degree of complexity in landform, geology, mineralogy, and groundwater, under conditions of a prevailing climate, developed on and in the materials in the terrestrial environment, at their most complex geological and lithological expression, will express this degree of geological complexity at the coast if the same geological system crops out at the coast, with the added factor that coastal physical, chemical and biological processes superimpose other features on them. Thus the geological and geomorphological units of the terrestrial environment generally become more complex where they interface with, or are transformed at their interface with the sea.

In coastal situations, soils mostly are stripped away from rocks at the shore, but if still present, they can become involved in complex hydrochemical interactions at the coast (driven, for instance, by sea spray, and groundwater seepage).

As the interface between land and sea, the coastal zone is subjected to a range of physical, chemical and biological processes, often graded in intensity normal to the shore gradient. Those occurring in Western Australia are listed in Table 4.1 (though the general information on coastal processes has been drawn from Johnson 1919; King 1972; Schwartz 1972, 1973, 1982, 2005; Ginsburg 1975; Davidson-Arnott & Greenwood 1976; Klein 1976; Davies 1980; Bird & Schwartz 1985; Inden & Moore 1983; Greenwood & Davis 1984; Kelletat 1995; Black et al. 1998; Komar 1998; Woodroffe 2002; Semeniuk 2005).
Table 4.1: Main physical, chemical, biological processes operating in coastal zones

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
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<tbody>
<tr>
<td>wave action, comprising swell of various periods, wind waves, and standing waves, resulting in a plethora of wave patterns and wave lengths, variable temporally and spatially, and variable normal to the shore in terms of translational waves, shoaling waves, and breaking waves, with their attendant effects of erosion, sediment mobility, particle-size sorting, sedimentary structure development; this is a prevailing phenomenon at the shore;</td>
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<tr>
<td>storm action, and associated storm surges, with their attendant effects of erosion, sediment mobility, particle-size sorting, sedimentary structure development, amongst other effects; this is an episodic phenomenon at the shore;</td>
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<tr>
<td>cyclone activity and associated surges, with their attendant effects of erosion, sediment mobility, sedimentary structure development, amongst other effects; this is an episodic phenomenon at the shore;</td>
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<tr>
<td>tsunamis and seismic-related sea surges, with their attendant effects of erosion, sediment mobility, sedimentary structure development, amongst other effects; these are episodic phenomena at the shore;</td>
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<td>longshore drift with its attendant effects of sediment mobility and particle-size sorting;</td>
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<tr>
<td>rip currents with their attendant effects of sediment mobility, particle-size sorting, and development of bedforms and sedimentary structures;</td>
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<tr>
<td>development of a splash zone; this is a prevailing phenomenon at the shore;</td>
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<tr>
<td>onshore winds, acting on the near-shore marine water body, resulting in shore-directed wind waves, longshore drift, and other currents, and seiches; these are commonly linked to seabreezes/landbreezes systems</td>
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<tr>
<td>onshore winds acting on the upper shore face of sandy coasts, with their attendant effects of erosion, sediment transport, particle-size sorting, lag development, and dune building;</td>
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<td>shore sedimentation physically mediated by river influx, longshore and/or onshore wave transport, and tidal currents;</td>
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<tr>
<td>shore sedimentation biologically mediated by in situ or proximal skeletal production (mainly carbonate, but also siliceous such as from diatoms and radiolarians);</td>
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<td>pronounced bioerosion;</td>
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<td>chemical erosion of susceptible minerals and materials;</td>
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<tr>
<td>wetting and drying in the splash zone and the high-tidal zone;</td>
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<tr>
<td>salt weathering, particularly in high tide zones, and splash zones;</td>
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<tr>
<td>diurnal to semi-diurnal tidal inundation, and attendant tidal-current processes that result in erosion, sediment mobility, particle-size sorting;</td>
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</tr>
<tr>
<td>diurnal to semi-diurnal invasion of coastal sedimentary bodies by seawater during high tide;</td>
<td></td>
</tr>
<tr>
<td>evaporation of pore water and shallow groundwater in high-tidal zones during low tide and neap tides, driven by solar radiation and/or wind, to develop moisture gradients and salinity gradients, and hence biological gradients and geochemical gradients;</td>
<td></td>
</tr>
<tr>
<td>transpiration, resulting in depletion of pore water and shallow groundwater in high tidal zones during low tide and neap tides to develop moisture gradients and salinity gradients;</td>
<td></td>
</tr>
<tr>
<td>hydrochemical effects such as precipitation of calcium carbonate (aragonite or calcite), gypsum, or halite, where evaporation has markedly concentrated coastal groundwater and pore water;</td>
<td></td>
</tr>
<tr>
<td>hydrochemical and geochemical effects such as solution;</td>
<td></td>
</tr>
<tr>
<td>fresh-water seepage in the subsurface through appropriate aquifers into sandy coastal zones with its attendant effects of coastal erosion</td>
<td></td>
</tr>
<tr>
<td>fresh-water seepage in the subsurface through appropriate aquifers into the coastal zone with its attendant effects on coastal ecology;</td>
<td></td>
</tr>
<tr>
<td>fresh-water surface discharge onto the coastal zone;</td>
<td></td>
</tr>
<tr>
<td>sediment delivery to the tidal zone by fresh-water discharge onto the coastal zone;</td>
<td></td>
</tr>
<tr>
<td>flora habitation, and its material contribution, encrustations, and bioturbation;</td>
<td></td>
</tr>
<tr>
<td>fauna habitation, and its attendant material contribution, encrustations, biostrome and bioherm building, and bioturbation!</td>
<td></td>
</tr>
</tbody>
</table>

1. For discussion of biostromes and bioherms see Cummings (1932), Nelson et al. (1962), and Kershaw (1994).
2. Shoreline erosion and other shoreline processes induced by ice crystallisation and thawing are noted in arctic shorelines but do not occur in Western Australia.
Many of the processes listed in Table 4.1 are absent in the terrestrial environment. Those that do occur (e.g., chemical erosion of susceptible rocks/materials, hydrochemical and geochemical effects such as precipitation of calcium carbonate, and hydrochemical and geochemical effects such as solution of specific minerals), particularly along the shores of lakes and playas, are more amplified in the coastal zone, or because there is interaction with seawater, the effects of the processes are manifested differently.

The significant feature to note from Table 4.1 is the prevailing nature of many of the interacting processes in the coastal zone, the short-term temporal variability of some processes (e.g., Allen 1984 discusses the temporal variability of processes along the coastal zone), and those processes that are not present in other Earth environments (viz., oceanic wave action, or daily tides, and seabreezes/landbreezes). Many of the processes are acting concurrently. Aquatic or wetland terrestrial environments (such as salt lakes and rivers) exhibit some of these processes resulting in complexity along their shores (particularly salt lakes because of their hydro-chemistry) but generally not to the same degree as marine coastal zones. Further, the periodicity of some of the processes in coastal environments is generally not equivalent to terrestrial environments. Where there is similarity of periodicity, the processes are of a different nature. For instance, the annual effect of storms on a sand-and-mud coast temporally may be viewed as equivalent to the annual flooding of a sand-and-mud river system, but the actual processes and lithologies generated are markedly different.

To illustrate the added complexity a coastal setting provides in contrast to a partly-equivalent terrestrial system, the processes operating and the geodiversity developed in an inland dune system in an arid region are compared to dunes in a beach-dune coastal system. An inland dune system can be variable and complex at the medium scale down to lamination scale and grain-packing scale, with landforms, sedimentary structures, and grain packing varying in response to temporal changes in wind direction and wind intensity (resulting in laminae formed by grain fall, slip-face avalanche, traction, saltation, particle sorting, winnowing, rippling, and ripple-migration; Bagnold 1941; McKee 1979; Brookfield & Ahlbrandt 1983; Allen 1984). These dunes may be flanked by geomorphically and lithologically distinct inter-dunal systems (usually of inter-dune flats; Glennie 1970; Kocurek 1981; Lancaster 1988). For coastal dunes, notwithstanding that they are commonly bordered after progradation by stranded dunes (which may undergo increasing diagenesis towards inland), and to seaward by a beach, such dunes essentially carry the same set of processes and develop the same set of sedimentary structural and grain-packing features as arid-region dunes but have added complications with grain behaviour and grain packing as a result of their content of equant to platy carbonate grains and porous carbonate grains. Further, coastal dunes are bordered by a complex stratigraphy to seawards and in the environments encompassed by the nearshore, swash zone, berm, and foredune. As such, while the coastal dunes themselves may be more or less comparable to the inland arid dunes in terms of geomorphology and sedimentary structures, the package of a coastal beach-dune system will show more geodiversity in terms of geomorphology, sediments, and stratigraphy than inland arid-zone dunes and inter-dune flats located in an arid desert region.

Another feature which sets the coastal zone apart from terrestrial environments is the extent of biological activity, such as skeletal production, trapping and binding in a sedimentologically dynamic system, boring, bioturbation, and mediation of diagenetic effects. Skeletal grain production can have an effect on sedimentation patterns regionally: with increased skeletal grain production, sediments can change from siliciclastic to a siliciclastic-carbonate mixture to wholly carbonate in composition. Biogenic particle content may dominate over siliciclastic particle content at the local scale, or may dominate sedimentary patterns regionally. This latter situation is exemplified, for instance, by the carbonate sediments and reefs of Shark Bay, the west coast of the Persian Gulf, the Bahama Banks, Florida Banks, and the Great Barrier Reef (Davies 1970; Logan & Cebulski 1970; Logan et al. 1970; Purser 1973; Logan 1974; Bathurst 1975; Scholle et al. 1983; Tucker & Wright 1990). So while siliciclastic sediments and sediments can share common physical processes in the shore zone (viz., wave action, tidal-current effects, aeolian effects, amongst others), and thus can generate the same suite of physical sedimentary structures such as layering, cross bedding, and ripple drift lamination, if biogenic processes and products become dominant, they add a specific signature to products. And while siliciclastic sediments (accumulating either in the coastal or terrestrial
environments) can form environment-specific fine-scale to large-scale complex sequences in their own right, if biological effects begin to exert an influence, biogenic structures such as burrows and bioturbation may become dominant.

While all the interactive processes that can operate on accumulations of siliciclastic sediments in the coastal and terrestrial environment are present in the carbonate coastal suite, there is the added factor in the carbonate sediment suite that carbonate minerals such as aragonite, Mg-calcite and calcite (because of their relative and differential solubility) may hydrochemically and biologically interact with the environment to a greater extent than do siliciclastic sediment particles, i.e., carbonate sediments are more susceptible to diagenesis than siliciclastic sediments. For example, carbonate grains are susceptible to algal micro-boring and marine weathering, and there is a large range of diagenetic products developed in the tidal zone (Logan 1974; Bathurst 1975; Tucker & Bathurst 1990; Tucker & Wright 1990).

Additionally, coasts commonly exhibit gradients normal to shore, e.g., a gradient in inundation and evaporation, with attendant gradients in wave energy and tidal energy, and hence a graded expression of processes of sedimentation, erosion, and hydrochemical effects. This results in variable, complex and diverse physical, geochemical and biological products across the shore, and variation in fine- to small-scale stratigraphic sequences. As a consequence, many of the processes listed in Table 4.1 operating in the coastal zone, result in a gradational array of products across the coastal gradients. Responses to a concentration gradient in hydrochemistry is an example: there is precipitation of carbonate minerals and gypsum from high neap tide and high spring tide to highest tidal level. The discharge of fresh water into the coastal zone, where it mixes with seawater, or concentrated seawater, also can result in a range of chemical gradients and products, such as precipitates, or in biologically-mediated chemical changes. The discharge of fresh water in the coastal zone, with a rise and fall of the water table, particularly along steep, sandy beach shores (Clarke & Eliot 1987; Horn 2002), can also result in the erosion and accretion of the shores, and in the diurnal development of shoreline beach cusps (Kuenen 1948; Mii 1958; Guza & Inman 1975; Werner & Fink 1993; Komar 1998; Coco et al. 1999; Short 1999), with their resulting complex meso- and micro-stratigraphy and sedimentary structures (Mii 1958).

Both sandy beaches and tidal flats exhibit stratigraphic and sedimentological complexity, with the degree of complexity to some extent related to climate and oceanographic setting (for instance, beaches in tropical climates can develop beach rock, and signatures of cyclone activity through development of beach-rock boulder ribbons; cf. Semeniuk 2008).

Sandy beaches provide excellent examples of the products of wave and tidal energy intersecting a sloping shore, and illustrate the range of sedimentary products that are developed across the slope gradient from shallow subtidal to supratidal, in response to the graded effect of waves, tides, wind and fresh-water seepage (Beall 1968; Clifton 1969; Clifton et al. 1971; Reineck & Singh 1971; Davidson-Arnott & Greenwood 1976; Semeniuk & Johnson 1982; Inden & Moore 1983; Allen 1984; Semeniuk 1996b,1997; and see later). For instance, wave action intersecting a sloping shore is translated to a lower flow regime (varying progressively upslope) to upper flow regime, and the resultant development of rippled beds, megarippled bedforms, and plane beds, respectively. Hourly, daily, weekly, and seasonal variation in wave patterns, coupled with storm effects, tide fluctuation, and onshore winds, generates lamination, shell layers, cut-and-fill structures, discontinuities (Mii 1958; Panin 1967; Boothroyd 1969), variation in grain size across laminations, and bubble sand. Biological activity results in shell layers, burrows, and bioturbation.

Tidal flats generally provide a greater degree of stratigraphic and sedimentological complexity than beaches because often they are sedimentary environments wherein there is accumulation and interaction of mud, sand, gravel, and biogenic material (Semeniuk 2005), and so are used here to illustrate the sedimentological and stratigraphic intricacies that can be developed along the shore zone. Tidal flats may be muddy, sandy, gravelly, or covered in shell pavements, and compositionally they may be underlain by siliciclastic or carbonate sediments or their mixtures. Depending on climate, tidal level, substrate and salinity, tidal flats may be covered by salt marsh, mangroves, sea grass, algal mats, microbial mats, biofilms, as well as mussel beds, oyster beds and reefs, and worm-tube beds and reefs,
and inhabited by a burrowing benthos of molluscs, polychaetes, and crustacea (Semeniuk 2005). Tidal flats are rich in processes and products resulting from oceanographic, sedimentological, geohydrological, hydrochemical, and biotic interactions (Klein 1963, 1976; Ginsburg 1975; Alexander et al. 1998; Black et al. 1998). As lower-energy systems with less scope for physical reworking, they develop a profusion of natural history coastal features reflecting the products of daily tidal inundation, prevailing translating/shoaling waves, wind, evaporation, and biogenic reworking. For instance, there are the sedimentologic products of interactions between waves and tides (e.g., cross-laminated sand, ripple-laminated sand, lenticular bedding, flazer bedding, laminated mud, ripple-laminated silt in clay), the products of interactions between sediments and biota (e.g., various burrow forms zoned tidally across the shore, various types of root-structuring, skeletal remains related to tidal levels), the geomorphic products of tides (e.g., tidal run-off on low-gradient slopes to form meandering tidal creeks), and the products of hydrochemical interactions with sediments (e.g., dissolution of carbonate by acidic pore water; cemented crusts and their intraclast breccia derivatives; carbonate nodules; gypsum precipitates; and products of redox reactions such as biologically-mediated precipitation of iron sulphide). The tidal flat zone is so sedimentologically diagnostic that for stratigraphers and students of sedimentary rocks, identifying this environment in the geologic record is often an important first step in the reconstruction of palaeo-environments, the location of facies associated with coastlines, and the recognition of such markers in stratigraphic sequences in basin analyses (Semeniuk 2005).

At the next scale, the scale of meso-stratigraphic and larger, the stratigraphic products and geomorphic products of coasts are unique from another perspective, that of recording sea level changes and climate changes: coasts interface with oceans, and oceans, as the receiving basins of solar radiation, can propagate to the shore their history via sea temperatures, wave climate and storms. They also can imprint on the shore their record of sea level changes. With progradation, the coastal zone thus has the potential to register and preserve a variable, complex and fluctuating oceanic and climate history from erosional products, sedimentation products, geomorphology (e.g., beach-ridge patterns and cheniers, amongst others), and fossil biota. Through the recognition of appropriate sea-level indicators (or markers), coastal-zone stratigraphy, coastal-zone geomorphology, progradational shores, and rocky shores also have the potential to preserve records of sea-level changes (for Western Australia, see Semeniuk 1985a; Semeniuk & Searle 1986; Playford 1988; Semeniuk 1996b, 1997; and Semeniuk 2008).

A selection of products specific to the coastal zone that particularly well illustrate the special nature of the shore is listed below in Table 4.2 in terms of stratigraphy, sedimentary structures, lithologic products, biogenic structures, and diagenesis.
Table 4.2: Some products specific to the coastal zone (ordered in decreasing scale)

<table>
<thead>
<tr>
<th>Stratigraphic products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example 1: upward-shoaling sequence developed by a prograding sandy beach where an inclined shore interfaces, interacts and interacts with waves, tides, onshore winds and storms; this is one of the best developed of coastal stratigraphic sequences, as it brings into focus the interplay of coastal processes, sediments, biota, and hydrochemistry (Beall 1968; Clifton 1969; Clifton et al. 1971; Semeniuk &amp; Johnson 1982; Inden &amp; Moore 1983; Allen 1984; Semeniuk 1996b, 1997); depending on climate and tidal range, the stratigraphic products can change latitudinally, e.g., occurrence of beach rock and cyclone-generated sediments (Semeniuk 1996c, 2008)</td>
</tr>
<tr>
<td>Example 2: upward-shoaling sequence developed by prograding siliciclastic tidal flat grading granulometrically from low-tidal sand, to muddy sand to high-tidal mangrove-vegetated mud; this sequence is one of the best developed of coastal stratigraphic sequences, because it provides a plethora of sedimentary and stratigraphic products that result from a wide range of grain sizes, stronger effect of tides across tidal gradients, stronger effect of biota because of the relatively lower energy setting, and the effects of hydrochemistry graded across tidal flats (Thompson 1968; Ginsburg 1975; Semeniuk 1981b; Semeniuk 2005); again, depending on climate and tidal range, stratigraphic products can change latitudinally, e.g., occurrence of displaceable gypsum and development of mangrove facies (Brown &amp; Woods 1974; Logan 1974; Semeniuk 2005)</td>
</tr>
<tr>
<td>Example 3: upward-shoaling sequence developed by prograding algal-mat/stromatolites on carbonate and evaporate tidal flat (Kendall &amp; Skipwith 1969; Shinn et al. 1969; Logan et al. 1974)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lithologic products</th>
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</thead>
<tbody>
<tr>
<td>Example 1: beach rock conglomerate and breccia (Semeniuk 1996c, 2008)</td>
</tr>
<tr>
<td>Example 2: shoreline coquina (Logan et al. 1970)</td>
</tr>
<tr>
<td>Example 3: intraclast breccia sheet (Hagan &amp; Logan 1974; Logan 1974)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sedimentary structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example 1: tidal flat sedimentary structures and layering such as bidirectional ripple cross-lamination, flazer bedding (Reineck &amp; Singh 1980; Shinn 1983)</td>
</tr>
<tr>
<td>Example 2: flazer bedding (Reineck &amp; Singh 1980)</td>
</tr>
<tr>
<td>Example 3: bubble sand within an upward-shoaling beach sand sequence (Emery 1945; Semeniuk &amp; Johnson 1982; Inden &amp; Moore 1983; Semeniuk 1997)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Biogenic structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example 1: U-shaped faunal burrows (Reineck &amp; Singh 1980)</td>
</tr>
<tr>
<td>Example 2: stromatolitic layering and emergent structures showing smooth, tufted and pustular fabrics (Logan et al. 1974)</td>
</tr>
<tr>
<td>Example 3: lithophagic borings (Semeniuk &amp; Johnson 1985)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diagenetic products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example 1: beach rock, cemented bands or layers (Ginsburg 1953; Semeniuk 1996c, 2008)</td>
</tr>
<tr>
<td>Example 2: nodular gypsum replacing carbonate tidal flat sediments (Kendall &amp; Skipwith 1969; Shinn 1983)</td>
</tr>
<tr>
<td>Example 3: precipitate aggregates forming nodules on shells or crustacean skeletons (Semeniuk 1980a, 1981a, 1981b)</td>
</tr>
</tbody>
</table>

In the context of Table 4.2, in order to provide a perspective of the diversity and complexity of sedimentary structures and fine- to small-scale stratigraphic sequences in the coastal zone compared to terrestrial environments and deeper water marine environments, a review of variety of text books and sedimentological references that illustrate sedimentary structures and fine- to small-scale stratigraphic sequences from a diverse range of depositional systems was undertaken (Allen 1984; Bathurst 1975; Berger 1974; Bird & Schwartz 1985; Cas & Wright 1988; Collins 1988; Collinson & Thompson 1982; Cooke & Warren 1973; Conybeare & Crook 1968; Davies 1970; Davies 1980; Davis 1978, 1994; Davis & Ethlingon 1976; Duncan et al. 1992; Fisher & Smith 1991; Ginsburg 1975; Ginsburg & James 1974; Greenwood & Davis 1984; Hopley 1982; Inden & Moore 1983; Kelletat 1995; Kendall & Skipwith 1969; Klein 1976; Le Blanc 1976; Logan 1970, 1974; Matthews 1984; Middleton 1965; Morgan 1970; Pettijohn & Potter 1964; Potter et al. 1980; Purser 1973; Reading 1978; Reineck & Singh 1980; Rigby & Hamblin 1972; Scholle & Spearing 1982; Scholle et al. 1983; Semeniuk 1980a, 1981b, 1996c, 1997, 2008; Semeniuk & Johnson 1982, 1985; Shinn 1983; Shinn et al. 1969; Snead...
While there is a degree of overlap, and some of the sedimentological and stratigraphic features dominant in coastal settings can occur in terrestrial sedimentary settings, though they are uncommon (e.g., water escape structures, bubble sand, U-shaped burrows), the coastal environments provide the greatest diversity and complexity of physical, chemical and biological structures and products and environment-specific features. Bubble sand provides an illustration of this: bubble sand (as small trapped air pockets in sand) can occur in shoreline deposits adjoining lakes, and locally on sandy levees, but it is uncommon. However, it is prevalent on coasts where there is wave action and a rising tide on a sandy beach – here it is a diagnostic feature of the upper-tidal zone of the beach (Semeniuk & Johnson 1982; Inden & Moore 1983; Semeniuk 1997).

The complexity, and development of environment-specific sedimentary structures and fine- to small-scale stratigraphic sequences are particularly evident biologically. This is because different areas of the Earth’s coastal environments, depending on biodiversity (related to biogeography), climate, and type of coastal system, have varying coastal biota, and biota often form particular assemblages across the shore in response to gradients in wave energy, tidal level, salinity, substrate type, and grain size, amongst others (e.g., mangroves in tropical muddy environments, saltmarsh in temperate muddy environments, mussel beds in low-tidal muddy environments). Some biota in specific settings develop coastal (tidal) biostromal or biohermal accumulations, for example, biostromal mussel beds (in The Wash and along the coast of North Wales, and the Wadden Sea; Yonge 1949; Evans 1965; Wolff 1983), or serpulid worm (biohermal) reefs (along the coasts in Eire, Scotland, and the Gulf of Mexico; Andrews 1964; Bosence 1973, 1979; Ten Hove & van den Hurk 1993).

To further illustrate the complexity of interacting processes and diversity of products that develop across a shore environment in contrast to terrestrial environments, several examples of sedimentary coastal systems and rocky-shore systems are described and compared below to (approximately) equivalent materials and sequences in terrestrial environments to contrast their geodiversity. For instance, upward-fining sequences involving sand and mud from a point bar is compared to an upward-fining sequence involving sand and mud from a tidal flat. In the range of comparisons provided, there has been an endeavour to remain within the same climate setting as there has to be some measure of internal consistency in the environmental setting for comparisons to be meaningful.

It is this range of sedimentological, erosional, and diagenetic features, described above, and their strength of development that sets coastal geoheritage apart from continental (or inland) geoheritage.

Comparisons of the coastal zone with inland systems – a contrast of geodiversity
A range of rocks, sediment sequences, and lithologies occurring in the coastal zone are compared to terrestrial environments. Some of the comparisons are of directly equivalent rocks exposed in coastal and terrestrial environments. For sedimentary sequences, the comparisons are between coastal sediments and their stratigraphic sequences and sediments and stratigraphic sequences occurring in broadly lithologically similar materials in terrestrial environments. The comparisons are intended to highlight the complexity and geodiversity of one environment in relation to the other. The examples are as follows (Figure 4.1):

1. a comparison between a fluvial ravine and a rocky shore using the Tumblagooda Sandstone (Opik 1954; Hocking 1991) as the parent material;
2. a comparison between a natural inland cliff/ravine and a rocky shore using a Pleistocene calcarenite as the parent material;
3. a comparison between an upward-shoaling stratigraphy of a point bar and an upward-shoaling tidal flat stratigraphy; and
4. a comparison between the micro-stratigraphy of a mud-dominated floodplain and mud-and-sand floodplain and that of a mud-dominated tidal flat.
The multiplicity of interacting processes operating on a sandy beach and on a calcarenitic rocky shore is illustrated in Figures 4.2 & 4.3.

The Tumblagooda Sandstone exposed along the coastal rocky shores of mid-western Western Australia shows a wide variety of small-scale and fine-scale features not evident in the same Formation in fluvial ravine settings. Of particular importance is the effect of salt weathering in the coastal zone resulting in better exposure of lithology and sedimentary structures (Figures 4.1A to 4.1D), the development of tafoni, structural benches (where bedding-plane features are well exposed), the wave-cut benches, pavements and slopes planed by marine processes, and the intertidal cementation. Structural benches exposing bedding-plane features on soft lithology such as shales are recessively weathering in the fluvial ravines.

The contrast in geodiversity for Pleistocene calcarenites between natural inland cliff/ravines and the coastal zone is similar (Figures 4.1E to 4.1H): the coastal exposures show more geodiversity than calcarenites occurring in inland exposures in terms of small-scale and fine-scale geomorphology, and in effects of coastal diagenesis. The coastal outcrops are also better exposed as a result of wave-washing, wind erosion, and salt weathering.

The difference in geodiversity between a sedimentary sequence developed in an upward-shoaling tidal flat and that of an upward-shoaling stratigraphy of a point bar also is marked, with the former illustrating the products of intricate interaction between waves, tide, wind, and biota, and the latter showing a less developed assemblage of sedimentary structures and lithology (Figures 4.1E to 4.1H). The intricacies of physical, chemical and biological processes acting on tidal flats result in suites of lithologies, sedimentary structures and sedimentary products not developed in the point bar (Figures 4.1I-4.1J). In fact, the point bar, without a fluctuating floodwater level is a relatively simple stratigraphy and sequence of sedimentary structures. The final example, contrasting the micro-stratigraphy of a mud-dominated tidal flat with the micro-stratigraphy of a mud-dominated floodplain and a mud-and-sand floodplain shows, again, that the tidal-flat sequence in terms of sedimentary structures, lithology and biological effects is more complex and diverse, reflecting the interaction of particle sizes, tides, waves, inundation frequency, hydrochemical gradients, and biota (Figures 4.1K & 4.1L). Even though the scale of stratigraphy is somewhat different, the floodplain sequences show relative monotony of lithology, while the tidal flat mud sheet shows relative richness of features at the fine scale evident as lamination, burrows, burrow-mottling, flazer bedding, mud cracks and mud flakes.

Differences between coastal and terrestrial environments are well highlighted by contrasting a sandy beach system with fluvial sands. There is a marked difference in geodiversity between a sedimentary sequence developed under a beach in a microtidal setting, in terms of lithology, structures, and small-scale stratigraphy, in comparison to sand shoals in sand-dominated river systems. As mentioned earlier, the beach sequences show the graded effect of waves, tide, wind, and biota on a sandy slope. There can be hourly, daily, and weekly to seasonal adjustment of the beach profile in response to waves, the formation of beach cusps, and the cutting of cliffs in sand, as well as seasonal accumulation of storm deposits, amongst other effects, with the result there is a complicated layered and cross-layered stratigraphy, and scour-and-fill structures, bounded by discontinuities (Mii 1958; Panin 1967; Boothroyd 1969). Beach processes, sedimentology, and stratigraphy are summarised in Figure 4.2. In contrast, sand shoals in sand-dominated river systems exhibit a much less complicated sequence of laminated and cross-laminated sands (Reineck & Singh 1980). More complex stratigraphy in such systems occurs where there are lag concentrates of coarse sand and gravel, and where mud accumulates (and then dries and desiccates) in the troughs between megaripples and shoals.

In the examples presented above, the coastal zone manifests lithologically better exposed rocks and stratigraphic sequences, and sedimentologically more complex products and stratigraphy than the terrestrial environments.
This emphasis on the coastal zone is not intended to diminish geological complexity elsewhere. Other environments do have geodiversity, and it may be expressed in a variety of ways, e.g., coastal landforms in volcanic settings, karst environments, , and landscapes developed by arid zone erosion.

**The main processes leading to development of coastal types**

To provide a context for the development of category-oriented coastal types for Western Australia, the main end-member processes that develop the different coastal forms and shore types are described. Identifying the main end-member processes ensures that all forms of coasts are captured at a high order level of classification.

The main processes that determine coastal forms and shore types were identified from reviewing the global, Australian, and Western Australian literature on coastal systems, and from information deriving from the fieldwork as described in the Methods. Some of the processes and products specific to Arctic regions were not addressed in this Thesis as Western Australia traverses only climates from Tropical to Temperate.

In Western Australia, there are five main and ubiquitous end-member marine and coastal processes that develop coastal forms and shore types (Table 4.3); listed in generally decreasing scale, these are:

- marine inundation
- erosion
- sedimentation
- biogenic processes
- diagenesis

Globally, there is a sixth process that can form coasts, viz., volcanism. Volcanism builds islands (with their peripheral coasts), or through ash accumulation, cone accretion, or lava flows encroaching from a mainland into the sea develops coasts constructed of volcanic materials. This is not a process operating in Western Australia, and is outside the scope of this Thesis.

**Table 4.3: The five main end-member processes and resultant coastal forms in Western Australia**

<table>
<thead>
<tr>
<th>Process</th>
<th>Examples of resultant coastal form or product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine inundation</td>
<td>coastal form reflecting pre-inundation topography (e.g., fluvially dissected landforms that will develop a ria coast, or shore-parallel limestone ridges which will develop a limestone barrier coast)</td>
</tr>
<tr>
<td>Erosion</td>
<td>cliffed (straight) coasts, cliffed (crenulated) coasts, coves and embayments, headlands, stacks, benches, platforms, notches, lapiés, fissures</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>deltas, beach ridge plains, barrier islands, beach/dune shores, tidal deltas, spits, cheniers, fans, breccia/talus deposits</td>
</tr>
<tr>
<td>Biogenic processes</td>
<td>coral reefs, serpulid reefs, oyster reefs, stromatolitic reefs</td>
</tr>
<tr>
<td>Diagenesis</td>
<td>beach rock ramps, cemented pavements, breccia pavements, gypsum pavements, gypsum crystal meshworks, sheets of gypsum rosettes, patina</td>
</tr>
</tbody>
</table>

Essentially in Western Australia, all coastal forms and products of erosion, sedimentation, biological coastal construction, and diagenesis are underpinned by the five end-member processes operating alone, in combination, or operating at different scales. A given tract of coast may have products of these processes developed to different extent and scale along the shore, and/or may have products of these processes alternating along the shore. These end-member processes are described below as to their significance in developing coastal types. The extent that a process is developed is dependent on basin setting, sediment supply, oceanographic setting, and climate. The scales at which the processes operate are shown diagramatically in Figure 4.4.
Marine inundation is a major factor in developing coastal landforms. If there has been no Holocene erosion or sedimentation, or only minor erosion or minor sedimentation superimposed on such coastal landforms, marine inundation would be the major determinant of a coast form. At the larger scales, where erosion and sedimentation are secondary factors in coastal development in that they influence the formation of smaller scale products, marine inundation in fact is a deciding factor in the development of coastal forms. An idealised diagram showing coastal forms initially developed by marine inundation of a topographically variable fluvially dissected hinterland, and some of the more common coastal forms developed by variation in erosion and sedimentation is presented in Figure 4.5.

Erosion is an ubiquitous process along the shore, and is another major determinant in the formation of many types of coastlines. With waves, tides, currents, chemical solution, and bioerosion as drivers, it can be a major determinant of coastal form. Coastal erosion cuts into mud deposits (e.g., King Sound tidal flats; Semeniuk 1981a), sand deposits (e.g., sand cliffs cut into Peron Sandstone; Logan et al. 1970), soft rock sequences (e.g., cliffs cut into the Toolinna Limestone along the Nullarbor Plain), hard rock sequences (e.g., cliffs cut into the Precambrian rocks along the Leeuwin-Naturaliste ridge), and into heterogeneous geological sequences (e.g., coasts cut into a plain comprised of Tertiary sediment and upstanding granitic inselbergs on the Esperance Plain). Erosion exposes formerly buried geological features, and if it is differential where it incises into a lithologically and/or structurally variable bedrock, it results in complexly shaped shorelines (e.g., the folded rocks of the King Leopold Mobile Zone bordering the Kimberley Basin in the Kimberley region; see later in Chapter 8). At one extreme, coastal erosion results in high rocky cliffs, with well-exposed geological sequences, and eroding sedimentary deposits at the other. It operates at the large scale to develop laterally extensive cliffs such as the Zuytdorp Cliffs, and the Baxter Cliffs along the edge of the Nullarbor Plain, and at the smaller scales to develop site-specific cliffs within a marine-inundated coastal terrain, or within a sedimentation-dominated coast. At the other extreme it results in smaller-scale erosional forms such as local cliffs.

Where sediment supply is adequate, regardless of whether it is marine-derived and directed shorewards, or land-derived and directed seawards, sedimentation can dominate the development of coastal form. It can be an extensive and ubiquitous process along the shore, developing many types of coastlines. For example, at the larger scales, sedimentation results in deltas, barrier dune systems, aeolian coasts, prograded beach/dune shores, tidal-flat systems, and estuarine deposits within gulfs and embayments. In boreal and arctic regions, coastal sedimentation can be driven by glacial processes. Sedimentation at the smaller scales, even if occurring within a dominantly eroding coast, results in shoreline spits and bars, pocket beaches, shoreline breccia deposits, and perched dunes. As such, sedimentation can be a major determinant of coastal form.

Erosion and sedimentation, alternating at various time frames from millennial, and greater than decadal, to daily, can result in a range of coastal forms. At large scales, it may be manifest in features such as channel switching in deltas, rows of cheniers on prograding tidal flats, truncation of beach ridge lines, and development of inland-transgressing parabolic dunes on accreting sandy coasts. At smaller scales, it can result in complex geometry of recurved spits, talus or breccia deposits at the foot of cliffs, and the daily formation and destruction of beach cusps and rip channels (and their attendant stratigraphic and sedimentary products), amongst others.

Biogenesis involving biogenic processes and skeletal production can result in resistant shore-face biogenic structures, such as coral reefs, serpulid reefs, or oyster reefs, which may be expressed as extensive shore-face features, or as patch reefs. Generally, while many biologically-generated resistant structures and accumulations (such as coral reefs) are subtidal features and would not be strictly considered as “coastal”, some very shallow subtidal biogenic deposits, or those that may have shoaled into the low intertidal zone (being exposed at low tide) can be considered to be biogenic coasts. These can develop into fringing reefs that are border landmasses and islands. But while biogenic processes as coast forming are included where reefs are concerned, most biological activity and contributions along the coast is a subset of sedimentation, erosion, and diagenesis. For example, macrobenthos shell production, and other microfaunal and microfloral skeletal production, contribute materials to develop skeletal gravel and sand, or carbonate or siliceous mud, and form sedimentary
deposits, with some shell production resulting in (sedimentary) biostromes. In this context, biogenesis (and biogenic activity) is part of sedimentation. The many other forms of biological activity in the coastal zone are subsets of erosion (viz., bioerosion), or diagenesis (e.g., algal boring of carbonate grains, or biologically mediated blackening of grains) and clearly not part of the processes that form coasts and shore types.

Diagenesis is the chemical, physical, or biological alteration(s) effected in sediments after their initial deposition, and during and after their lithification (Bates & Jackson 1987). It involves precipitation, solution, or chemical/mineral reactions. Diagenesis will also include alteration of sedimentary rock such as Quaternary limestone. Diagenesis can result in the development of a diagenetic rock (or diagenite; Bates & Jackson 1987). As a process, it can be instrumental in developing coastal forms, especially at the medium, small and fine scales, and many coasts and coastal geological features are diagenetic in origin, or have formed as the result of erosion and/or sedimentation acting in combination with diagenesis. Diagenesis is particularly important in developing coastal features along tropical and subtropical arid coasts, where, for example, tidal cementation of sand develops indurated shoreline ramps of beach rock. Diagenesis in Shark Bay, for instance, results in the cementation of high-tidal sediments to develop extensive crusts and breccia pavements that dominate the shore. In combination with erosion and sedimentation, diagenesis can form distinctive shoreline products; for example, shoreline sand cementation (to form beach rock), followed by cyclone-induced erosion (to rip up the beach rock and form slabs), and shoreward transport of the beach rock slabs to form a high-tidal shoreline ribbon of boulder conglomerate and breccia (Semeniuk 2008).

While marine inundation, erosion, sedimentation, and some aspects of organic reef-building have been identified previously by other authors as coastal-forming processes, to date, the recognition of diagenesis as developing coastal forms and coastal features has not been given enough emphasis, and has not been previously described as a significant coast-forming process. While diagenesis is a recognised process in modifying sediments, particularly at the grain-scale and structure-scale, and is demonstrably a prevailing and ubiquitous process in the coastal zone, it can be secondary to the other coast-forming processes. For instance, coastal erosion cutting cliffs into relatively porous limestone is accompanied by diagenesis whereby the splash zone and the interface between marine water and fresh water are zones of carbonate cementation which results in hard bands (manifest as pavements, platforms, and benches). Yet diagenesis can result in significant and extensive coastal features, and can influence the development of coastal form, and the evolution of a coast. For this reason, in this Thesis, products of diagenesis are included where they influence coastal form and coastal features.

Coastal classification can be complex because coasts are formed not by a single process but by a range of processes operating at different scales, and to differing extent. The five major coastal-forming processes outlined above can act largely alone, or in combination, and contribute to a different individual extent when in combination. Coasts geomorphically also can express a gradational trend in their process of formation: from (marine) inundation to erosional to depositional. This gradational trend is from inundated landscapes, where the primary pre-inundated landscape is still evident, regardless of the geological nature of the inundated hinterland, to those where erosional forms dominate the coastal morphology, to coasts that are partly erosional/depositional, and finally to those which are wholly depositional.

Within any suite of coastal forms, sedimentation and/or erosion, and biogenic and/or diagenetic processes, can result in coasts that express geohistorical features useful to reconstructing the history of the Earth, from Holocene to the Precambrian (viz., Holocene stratigraphy underlying prograded coasts, or Holocene erosional morphology such as rocky shores with platforms and benches, or where erosion acting on older, pre-Holocene rocks has provided well-exposed lithologies, structures, and stratigraphy, e.g., sea cliffs exposing pre-Holocene stratigraphy).

**Why is the coastal zone significant for its diverse geoheritage values?**

Geoconservation is concerned with the protection and management of geological sites for the preservation of special outcrops, palaeontological, mineral, and pedological localities, geoarchives that represent a page from the Earth’s history, locations where Earth processes are active, locations that are representative of the Earth’s geodiversity, and sites that are of cultural significance (Sharples 1995;
Barettino et al. 1999; Brocx & Semeniuk 2007; Brocx 2008; Erikstad 2008). The coastal zone is especially significant in a context of geoconservation because, as emphasised in this Thesis, of all the environments on the Earth’s surface, it is one of the most complex in terms of landforms developed, sedimentological processes and products, and diagenetic processes and products, manifesting high geodiversity of Holocene landforms, stratigraphy, sedimentology, and diagenesis. It also exposes some of the best and most detailed outcrops (globally, including Western Australia) where geological history can be readily investigated. Such exposures have the potential for high geoheritage significance, and indeed some cliff exposures already have been afforded global and national geoheritage significance either because of their geological importance (the cliffs in Dorset and East Devon, and along the Sussex coast in the United Kingdom), or because of their cultural importance (the unconformity at Siccar Point, Scotland).

As a result of the interactions between the various processes, and between processes and products along the shore compared to terrestrial environments and submarine environments, a large range of physical, chemical, structural, and biological features and environment-specific features occur in the coastal zone. In addition to the complexity of forms, the interactions of land, sea, groundwater and atmosphere along the coastal zone, occurring at all scales, result in a grade in sizes of many of the coastal products. For sedimentary bodies, this ranges from the (larger-scale) geometric forms of sedimentary deposits down to the scale of laminae and grains. For eroding rock sequences, this ranges from cliffs to benches to tafoni and micro-pinnacles (“lapiés”) to structures and grains etched out in relief to smoothed surfaces (Guilcher 1953; Semeniuk & Johnson 1985; Paskoff 2005).

In this Chapter, the reasons that the coastal zone generally has greater geodiversity in terms of geomorphology, sedimentology, and diagenesis than some of the other complex environments are highlighted. Because it is the “interaction zone” of a large number of marine, terrestrial, groundwater and atmospheric processes in contrast to terrestrial, marine and volcanic systems, there is variation of geological processes and products temporally and spatially, with the variation depending on the coastal setting, the extent of terrigenous influx, climate, biodiversity, shelter, wave climate, tidal range, and coastal wind.

Temporal variation in the coastal zone occurs in the time-frames of minutes, hours, days, weeks, months, and years for the processes involving waves, tides, winds, storms, cyclones, and fresh-water discharge. For sedimentary bodies, in short-term time frames, this can result in various expressions lithologically, and at the finer scales, in diverse sedimentary structures. In long-term time frames, this can result in changes in sedimentary style, stratigraphy, and sediment body geometry. Laminae in sand in the swash zone of beaches, varying in grain sizes or grain packing, can be reflecting variation in transport, winnowing, or grain-size sorting under the effect of waves and currents fluctuating in intensity in time frames of minutes or less. Annual storms, or cyclones returning perhaps on a decadal basis, can result in larger-scale sedimentological and stratigraphic responses such as the development of major scours and cliffs, development of shoreline spits, emplacement of gravel sheets and bars, or development of shell pavements by winnowing processes.

Spatial variation is from fine to small scales to regional scale (latitudinally). At fine to small scales, this may be expressed in shore-normal gradients in wave energy, tides, and hydrochemistry, that result in variation in geodiversity across the shore. Variation upslope in lithology, bedforms, and sedimentary structures reflect gradients in wave and tidal energy. Variation upslope in types of precipitates reflect gradients in hydrochemistry. At regional scales, spatial variability can be expressed in latitudinal (climatic) and environmental gradients, with other factors such as riverine influx and hinterland geology being equal. For instance, in Western Australia, latitudinal (climatic) gradients are expressed in the variation in landforms, coastal erosion, and diagenesis. Pleistocene calcarenites from their most southern occurrence along the Leeuwin-Naturaliste Ridge to their outcrop along the Zuytdorp Cliffs, a distance of over 1000 km, provide examples, with variation in outcrop form at the coast as the climate becomes more arid. There are changes in micro-topography of the rocky shore as the climate becomes more arid and marine waters become warmer, and changes in style and products of terrestrial and tidal-zone diagenesis as the climate becomes drier and the marine waters become warmer. Another example is provided by the Quindalup Dunes (Semeniuk et al 1989), which are the shoreline Holocene coastal dunes that stretch from Quindalup in Geographe Bay to Dongara (Figure
4.6). The variation within the Quindalup Dunes of Holocene coastal dune forms, landform assemblages, sediment types and their diagenesis, from their most southern occurrence to their most northern occurrence at Dongara (Semeniuk et al. 1989), shows differences expressed along a latitudinal (climatic) gradient. Changes in style of development of parabolic dunes illustrate this. Within this belt of Quindalup Dunes, Semeniuk et al. (1989) show that along the climate gradient, with change in wind direction and wind intensity, the coastal parabolic dunes change from short-axis easterly-ingressing generally simple and relatively small parabolic dunes in southern areas of the Swan Coastal Plain, to short-axis northeasterly-ingressing fretted larger parabolic dunes in central areas of the Swan Coastal Plain, to long-axis northerly-ingressing markedly attenuated (hairpin) and linearly extensive parabolic dunes in northern areas.

At the most fundamental level, leaving aside biogenic input, the coast modifies the hinterland by interacting with it. Being a ribbon environment, or viewed globally, a relatively thin linear environment, the coast traverses topography, variable geology and structures, oceanographic settings, climate of the coast and climate of the hinterland, tidal ranges, biogeography, and sedimentary style (e.g., delta-dominated, or barrier-dominated, or carbonate sediment dominated, amongst others). The coast is the most widespread linear environment on Earth. By definition it is circumferential to all landmasses facing the marine environment and thus inherently holds the largest potential to be the most variable environmental interface on Earth. And therein lies the reason for its geodiversity, and why coastal geohertiage within the umbrella of geohertiage has been emphasised in this Thesis. By way of contrast, volcanic systems, which earlier in this Thesis are recognised as having characteristics of high geodiversity, are not so consistently interconnected, even if portrayed as being in a “ring of fire” (e.g., the “Pacific ring of fire”; Sutherland 1995; Murphy & Nance 1998). They tend to create their own volcanic environment and its environmental subsets, and create their own range of products from magma interacting with bedrock geology, water and atmosphere. While exhibiting high geodiversity at the local scale, at the global scale volcanic systems tend to be nodal.

An outcome of the effect of erosion in the coastal environment is that coasts generally provide excellent locations for studying rock sequences (sedimentary, igneous, or metamorphic). Fine- to small-scale rock structural features, intra-lithologic features, and various lithologic types are brought out best by coastal erosion effected by wave washing, (sand-charged) wave erosion, wind erosion, and salt weathering. A corollary is that the exposures along the coast are often also the best outcrops for type sections and reference locations. The chalk cliffs of the southern coast of the United Kingdom, the stratigraphy exposed along the coast of Devonshire in the United Kingdom, the unconformity at Siccar Point in Scotland, and in Western Australia, the Tumblagooda Sandstone at Red Bluff, Kalbarri, the Broome Sandstone at Gantheaume Point, Broome, and the Toolinna Limestone along the edge of the Nullarbor Plains, exemplify this.
Chapter 5: Western Australian coast as a case study for coastal geoheritage

The coastline of Western Australia provides an excellent starting point for the development of a coastal classification for purposes of geoheritage and geoconservation as it manifests a wide variety of coastal forms along its 6000 km length and 22º of latitudinal range, a length that transcends (Figure 5.1) several geological regions (viz., the Kimberley region, the Canning Coast, though to the Eucla Basin), several climate zones (from tropical to near-temperate, and humid to arid), and various oceanographic and coastal settings (from microtidal to microtidal, from wave-dominated to tide-dominated to protected, to wind dominated). In contrast, as developed below, individual European countries, while trans-nationally complex, tend to involve only short segments of this subcontinental geological, climatic, and oceanographic variability as represented in Western Australia, and the western coast of the Americas, being currently and formerly a collision coast, while transcending a large latitudinal distance and climate belts, presents at the megascale a relatively uniform coastal form of uplift determined by tectonic plate collision.

To assess the usefulness of the Western Australian coast for developing coastal classification for purposes of geoheritage and geoconservation, several other coasts around the world are described for contrast. These are: the eastern Australian coast, the eastern coast of North America, the western coast of combined North and South America, the southern coast of Europe facing the Mediterranean Sea, and the east and west coasts of southern Africa. Emphasis is placed on describing the eastern Australian coast as it directly contrasts with the western coast.

The contrasts between the western coast of Australia and the eastern coast of Australia are illustrated in a series of maps in Figures 5.2-5.5. Figure 5.2 shows the contrasting geology of west and east coasts. Figure 5.3 shows the effects of the Great Dividing Range and its effect on coastal features along eastern Australia in contrast to western Australia. Figure 5.4 shows the humid setting of the east coast of Australia, compared to the more arid setting of the west coast, particularly the central west coast. Figure 5.5 shows a topographic relief map of Australia and the contrasting sectors around the coast that define the climatic, wave, tidal, and wind patterns.

For the eastern Australian coast, while geologically complex (Figure 5.2), as described below, the over-riding factors in coastal development are the effect of the Great Dividing Range (also known as the Eastern Highlands; Figure 5.3) and the generally wave-exposed shore. The eastern Australian coast also has a latitudinally prevalent humid climate - from north to south it has an annual rainfall from 3000 mm to 1500 mm, in marked contrast to that of the western coast which has a zone of aridity centred on the Tropic of Capricorn and grades to humid both northwards and southwards (Figure 5.4). As a result, the eastern coast of Australia has a distinctly different climate and oceanographic setting from the western coast (Figure 5.5). The Great Barrier Reef, located some 30-75 km offshore from mainland Australia, is not treated in this Thesis as part of coastal Australia.

The Great Dividing Range along the eastern part of Australia comprises an almost unbroken belt of higher ground, between 150 km and 450 km wide, extending from Cape York to Tasmania. It has a major effect on the physiography of eastern Australia and its coast, with short- and medium-sized rivers deriving from this highland discharging to the shore eastwards to develop a plethora of embayments and estuaries. The east coast of Australia is geologically complex and variable in that from north to south it is comprised of basins of various ages, mobile zones, and structural slivers, comprising Phanerozoic sedimentary rocks (sandstone, shale, conglomerate and limestone), volcanic rocks, intrusive igneous rocks, and locally (in northern Queensland and south-eastern NSW) Precambrian metamorphic rocks (Figure 5.2; Packham 1969; Jell 2013) and, consequently, the rocky shores expose much geodiversity in terms of lithology, structure, and ages. Because of the tectonic influence of a plate edge and volcanic activity associated with a plate margin, it has a general tectonic/structural grain that is oriented north-south, the exception to this general geological grain being the flat-lying rocks of the Sydney Basin. However, rocky shores are not developed continuously along the coast, except in local areas, but rather as isolated headlands, where resistant sandstone and volcanic rocks front the shore, separated by sandy stretches of coast and by estuaries. The north-south geological grain along the coast of eastern Australia influences coastal form in that the differential erosion of the rocks has resulted in development of coastal linear ridges, and the inter-
ridge areas form embayments or coastal lowlands wherein are developed J-shaped embayments (Langford-Smith & Thom 1969). While geologically variable, the eastern Australian coast has a recurring pattern of discontinuous rocky shores, headlands and intervening J-shaped sandy bays, and estuaries.

The eastern coast of North America has similarities with the eastern coast of Australia. The Appalachian Mountains form an inland ridge of highlands similar to Australia’s Great Dividing Range, from which derive numerous rivers that drain to the east to form a plethora of estuaries (Langford-Smith & Thom 1969; Fairbridge 1995). The Appalachian Mountains, though geologically variable from north to south, do not find expression at the eastern seaboard of North America, and the coast is dominated by young coastal sedimentary deposits. From north to south the coastal forms of barriers tend to be relatively similar.

The western coast of combined North and South America (excluding the narrow isthmus-like lands of Mexico) presents a distinctive and globally unique coastal tract. Geologically, they border the Pacific Tectonic Plate and Tectonic Nazca Plate, respectively (Uyeda 1978), with an intracratonic block uplift along a former zone of collision generating uplift (a Late Cretaceous to Palaeocene event called the Laramide Orogeny; Kluth & Coney 1981; Kluth 1986; English & Johnston 2004) resulting in the Rocky Mountain fold-and-thrust belt along the western part of the North America (including Canada) and a current zone of collision forming the Andes Mountain Chain along the western part of the South America (Press & Siever 1974; Long 1974; Uyeda 1978; Murphy & Nance 1999). These mountain chains traverse nearly the full range of Earth’s climate zones: from boreal to tropical (Canada, North America and Mexico in the northern hemisphere), and from tropical to sub-antarctic along South America in the southern hemisphere. The coasts of these zones fronting the Pacific Ocean are comprised of a series of cliffed shores, rocky shores, alluvial fans, narrow alluvial plains, short estuaries, fault-bound gulfs and peninsula, and fault-stepped terraces. While climatically variable, and with climate-influenced variability of coastal forms along the mountain chain zone, given that they span nearly the full latitude of both hemispheres, the coastal forms tend to be repetitive comprised of coastal plains, barriers and lagoons, numerous estuaries, rocky shores, cliff lines, local rias, and (at the climatic extremes) fjords.

Southern Europe is an alpine region formed during the Cainozoic to the present as a result of collision between the Eurasian Plate and the north-moving African Plate (Press & Siever 1974; Long 1974). From the perspective of plate tectonics, the northward migration of the African Plate into the Eurasian Plate in the Mediterranean basin is the most prominent aspect of the European tectonic geology today and the tectonic forces exerted by the African Plate is the major cause of the uplift of the Pyrenees, the Alps and the Carpathian Mountains (Plant et al. 2006). Southern, western, and northern Europe presently is composed of various crustal blocks representing different terranes and orogenies, which have been assembled over geological time (Plant et al. 2006). Apart from the extreme northwest where there is a fragment of the late Proterozoic terrane, initially part of a North American-Greenland landmass, most of the continental basement of Europe consists broadly of two large and distinct regions: a north and east stable Precambrian craton which finds expression at the coast, the Scandinavian Caledonides expressed as a highly dissected terrain at the coast to form a series of fjords, and to the south and west rocks of the mobile belt, comprising crustal blocks that have become successively attached to the ancient cratonic nucleus, which is the complex of rocks that faces the Mediterranean Sea and forms the Atlantic-Ocean-facing coasts of Portugal, Spain, France and the United Kingdom.

The mobile belt of rock of southern Europe along the zone of collision-and-uplift is a complex of folded, faulted, metamorphosed, and magma-intruded rocks (De Sitter 1956). The rocks are variable in age - from Palaeozoic, Mesozoic, to Cainozoic. The rock complex is manifest as the Swiss Alps, Italian Alps, and the belt of highlands that extend from Spain through Italy and Greece to the region of Afghanistan (Ager 1975, 1980; Matte 1991; Windley 1992; Plant et al. 2006) which have been dissected by post-uplift erosion, and inundated by Quaternary seas. As such, the southern margins of this tectonic complex of highlands, dissected highlands, and variable rock suites, where it faces the Mediterranean Sea has produced a coast that, while lithologically and structurally variable along its 4000 km longitudinal extent, expresses extensive rocky shores, peninsula, rocky ridge extensions as
islands, and ria coasts: the shore of Turkey is an exemplar. The geodiversity is inherent in the parent rocks, not in coastal forms. Further, while relatively similar in coastal form from west to east, the region of this coastal zone is largely located within the same latitude, and hence has a similar climate, i.e., subtropical (also commonly known as Mediterranean climate). Additionally, facing a relatively short fetch of the Mediterranean Sea, the coast has a different oceanographic setting and wave climate compared to coasts such as the eastern and western coasts of the Americas, Australia, and Africa which face the large seas of the Pacific, Atlantic, Indian and Great Southern Oceans with their extremely large fetches.

The east and west coasts of southern Africa are globally distinct coasts, though somewhat repetitive, expressed differently on the east side versus the west side (Maud 1980; Tinley 1985a, 1985b; Goudie 2010). In the tropical belt of the Earth, the east and west coast margins of southern Africa present to the Indian and Atlantic Oceans the largest occurrence of Precambrian rocks globally, mainly as a craton. Southern Africa also manifests a rifted passive margin backed inland by the Great Escarpment. Inland of the coast, because the coastal regions of southern Africa are not in tectonic collision zones (Press & Siever 1974; Long 1974), and because these regions are ancient geological terranes, they are comprised of relatively subdued terrain of low and moderate relief. Deriving from this terrain are a number of rivers. However, because much of the central coasts of southern Africa border deserts, run-off is also subdued (the deserts of Namib, for instance, extend to the coast; Tinley 1985a, 1985b; Goudie 2010). What drainage arrives to the coast develops small estuaries and embayments. But while there are local outcrops of Precambrian rock at the coast, particularly on the west coast, the overwhelming factor along the coast is that of sandy shores, with sand mobility driven northwards by the onshore prevailing winds and trapped by rocky headlands to form elongate J-shaped embayments. The east coast of southern Africa is a nearly continuous barrier dune system with intervening and small estuaries (Tinley 1985a, 1985b), and the west coast of southern Africa is a dominated by sandy stretches, north-migrating large barriers and spits, and small estuaries, and with little bedrock outcrop (Tinley 1985a). Consequently, the east and west coasts of southern Africa, with an underlying template of Precambrian cratonic rock, are comprised of relatively similar shores, different on the east to that of the west, but from a subcontinental perspective of relatively low geodiversity.

Other globally-distinctive coasts that have geoheritage significance that are of a markedly different character to those described above and to that of the Western Australian coast are the arctic and sub-arctic coasts of the northern hemisphere, including those of Norway, Sweden to Siberia and Canada, the fjord coasts of south-western Chile, the cliffed tectonic coasts of the Persian Gulf east shore, the low-latitude sedimentary coast and barriers along the Northern Sea bordering Poland, Germany and Holland, and the chalk cliffed coast of southern England and north-western France (Newell et al. 1951; Davies 1956; Ager & Smith 1965; Reineck & Singh 1967, 1971, 1972, 1980; Reineck & Wunderlich 1968; Millward & Robinson 1971; Perkins 1971; Purser 1973; Reineck 1975; Wolf 1983; Soper 1984; Goudie & Gardner 1985; Brunsden et al. 1988; Bennett 1989; Syvitski & Shaw 1995; Ellis et al. 1996; Semeniuk 1996c; Mortimore et al. 2001; Badman et al. 2003; Larkin 2006; Aarseth 1997; Aarseth, et al. 2008; Brunsden & Edmonds 2010; Nesje 2010; Reise et al. 2010; Brocx & Semeniuk 2011b; West 2011a, 2011b, 2012; Woods 2011; Cope 2012; Fredin et al. 2013).

The coast of Western Australia stands in contrast to all those coasts described above. While for most of its length it is not climatically unique in that many coasts globally traverse the climate gradient present along the Western Australian coast (i.e., from tropical humid to temperate humid, with a mid-western tract that is arid), there are some unusual and important aspects to the Western Australian climate and its coast. The southern coast of Western Australia, facing the Southern Ocean, and largely oriented east-west, is located latitudinally in a relatively consistent climate, though there is a climate gradient from temperate humid in the west to semiarid/arid towards the east. Also, the coast of Western Australia, climatically, is very different from the eastern coast of Australia in that it progresses from humid in the south to arid in central western tracts to humid in the north. The mid-western coast in fact is the most arid coast in Australia and one of seven arid coasts globally (Semeniuk 1996c).
Geologically, the coast of Western Australia is variable with a range of Precambrian and Phanerozoic sedimentary basins, Precambrian metamorphic belts (orogens) and Precambrian cratons (Figure 5.1). Each of these is a geological region, or province, or terrane, and has a corresponding coastal form. These are described in detail in the next Chapter, but a brief account is provided here for highlighting the significance of the Western Australian coast in terms of variability for geodiversity and geoheritage purposes. The regional coastal forms are, in fact, underpinned by this variable regional geology at the subcontinent scale (Woods 1980; Woods et al. 1985; Semeniuk 1995a). These geological regions, provinces or terranes also traverse the subcontinent of Western Australia latitudinally in large, extensive tracts so that they cross climate gradients (except those along the south coast) so that one part of a region or terrane is situated in a different climate to the other part, which is useful for investigating climate effects on coastal forms developed on the different parent rock types. Since each of the geological regions, provinces, and terranes are large, extensive, and distinct, large tracts or sectors of coasts, underpinned by and reflecting the geological region, province or terrane type, contrast as a coastal type from an adjoining coastal sector or province. When climate, oceanographic setting, wind regimes, and cyclones are superimposed on these geological regions and terranes, the various tracts of the Western Australian coast form distinct sectors. Also, since the geological regions and terranes are so extensive along the coast, within a given geological region or terrane there are long coastal tracts that span the gradients in climate providing the opportunity to investigate the same geological system in different climate settings. The Kimberley region, for instance, crosses climates of semiarid, subhumid and humid, the Canning Basin Coast crosses a climate gradient of arid, semiarid, to subhumid, and the Perth Basin coast crosses a climate gradient of humid to subhumid, semiarid to arid.

Compared to the rich variability of Phanerozoic rocks types exposed at coasts as in continental Europe and the United Kingdom, Western Australia with its cratons, orogens, sedimentary basins has long coastal tracts of very different and very distinct coastal forms. For instance, from north to south the range of coasts in Western Australia there is (Figure 5.1):

1. the extensive ria coast of the Kimberley region (Semeniuk 1993; Brocx & Semeniuk 2011b), spanning ~ 700 km of simplified coastal length;
2. the carbonate-dominated sedimentary system and rocky shores of the Canning Coast (Semeniuk 1993; 2008), spanning ~ 600 km of coastal length;
3. the heterogeneous arid Pilbara Coast (Semeniuk 1993, 1996c), spanning ~ 700 km of coastal length;
4. the gulf-and-ridge coast of the Carnarvon Basin, including Shark Bay (Logan 1970; Semeniuk 1993), spanning ~ 1000 km of simplified coastal length;
5. coves and estuaries, and the alternating sandy coast and limestone rocky shore of the Perth Basin coast (Searle & Semeniuk 1985), spanning > 1000 km; and
6. the south coast of rocky coasts, coves and estuaries and the Eucla coast (Semeniuk et al. 2011), spanning ~ 1200 km of coastal length. The heterogeneity and complexity of the Western Australian coast in relation to the geological regions is described in Table 6.2 in Chapter 6.

Table 5.1 below provides a brief description of the forty-four study sites listed in the Methods, Chapter 3, and further illustrates the variability of the Western Australia coast. These forty-four sites span the various gradients of climatic and oceanographic setting and the various geological regions of Western Australia. Each site is placed in its geological, climate and oceanographic setting, and described briefly as to its key coastal and geological features. Eight of the sites are treated in more detail in the Chapter on Application of the Geoheritage Tool-kit as described in the Methods.
The purpose of describing the forty-four sites along the coast of Western Australia was to document their variability with respect to geological, climatic, and oceanographic setting, and to obtain information at smaller scales on coastal features \textit{(i.e., to construct an inventory of geological features for a given locality)}. Thus these forty-four areas captured the full variety of coastal types in a range of geological settings, \textit{viz.}, the full climatic, and oceanographic settings of coastal Western Australia from tropical to near-temperate, from arid to humid, from wave-dominated, tide-dominated, to wind-dominated, and with sites from igneous rock provinces, sedimentary rock provinces, metamorphic/structural rock provinces, craton regions to sedimentary basins, and depositional coasts to erosional coasts.

The forty-four sites show the exceptional geodiversity of the Western Australian coast. Hence Western Australia is an ideal case study area to develop and apply a framework for coastal geoheritage assessment and conservation. The study of the forty-four sites provides an important first-level inventory, or coarse filter, of the coastal geoheritage of Western Australia to which classification and assessment procedures can then be applied. The diversity of coastal Western Australia as exemplified by the results of Table 5.1 also provides basis for the selection of the areas for the case studies.

One further feature of the Western Australia coast is that the range of coasts in a variable climate and oceanographic setting, occur in a geopolitically large area so that geoheritage principles can be derived from a single State-entity and can be applied without having to cross political and social boundaries. It enables development of principles of coastal geoheritage and geoconservation and its attendant policies within a framework of variable coastal types but with the application of a single policy framework.
Table 5.1: Description of the forty-four study sites along coastal Western Australia.

<table>
<thead>
<tr>
<th>Study Site</th>
<th>Geological region</th>
<th>Climate and oceanographic setting</th>
<th>Geological description and brief list of geoheritage essentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambridge Gulf</td>
<td>Boundary between Kimberley Craton and Sturt Block (Kraft 1977), and resides mostly on the Halls Creek Mobile Zone</td>
<td>Tropical semi-arid; macrotidal and wave-dominated</td>
<td>Funnel-shaped macrotidal estuarine gulf, with tidal flats, cheniers, tidal creeks, dynamic mid-channel tidal creek shoals, mangrove-vegetated lithotopes (Thom et al. 1975)</td>
</tr>
<tr>
<td>Kimberley Coast</td>
<td>Kimberley Craton</td>
<td>Tropical, semi-arid to humid; macrotidal and wave-dominated</td>
<td>Ria coast, with rocky shores, sediment-filled embayments, local beach ridges and beaches, tempestites, beach rock, biogenic shores, mangrove-vegetated lithotopes; see detailed case study of the Kimberley Coast geopark</td>
</tr>
<tr>
<td>King Sound</td>
<td>Boundary between Kimberley Craton and Canning Basin</td>
<td>Tropical semi-arid, macrotidal and wave-dominated</td>
<td>Funnel-shaped macrotidal estuarine gulf, with tidal flats, cheniers, tidal creeks, dynamic mid-channel tidal creek shoals, mangrove-vegetated lithotopes (Semeniuk &amp; Brocx 2011); see detailed case study of the King Sound geopark</td>
</tr>
<tr>
<td>Willie Creek</td>
<td>Canning Basin</td>
<td>Tropical, grading subhumid to semi-arid; macrotidal and wave-dominated</td>
<td>Embayment coast cut into Quaternary red sand (Mowanjum Sand), with local beaches, beach ridges and dune barrier along the sea-front, calcilutite fills the embayment; middle Holocene limestone deposits formed with sea level 1.5-2.0 m above present (Semeniuk 2008); see case studies for the Willie Creek coastal geosite</td>
</tr>
<tr>
<td>Broome region, focused on Gantheaume Point and Entrance Point at Broome, Dampier Creek, Black Rocks</td>
<td>Canning Basin</td>
<td>Tropical, grading subhumid to semi-arid; macrotidal and wave-dominated</td>
<td>Cliff coast cut into Mesozoic Broome Sandstone and Quaternary red sand (Mowanjum Sand), with local beaches and dune barrier and small embayments filled with calcilutite (Semeniuk 2008); see case studies for the Entrance Point coastal geosite</td>
</tr>
<tr>
<td>Roebuck Bay and Roebuck Plains</td>
<td>Canning Basin</td>
<td>Tropical, grading subhumid to semi-arid; macrotidal and wave-dominated</td>
<td>Megascale embayment cut into Quaternary red sand (Mowanjum Sand); embayment filled with calcilutite formed initially with sea level 1.5-2.0 m above present and progressively dropping to the present level (Semeniuk 2008); the seaward part of the Plain incised by shore-normal-tidal creeks</td>
</tr>
<tr>
<td>Barn Hill coast</td>
<td>Canning Basin</td>
<td>Tropical, arid; macrotidal and wave-dominated</td>
<td>Cliffed red desert sand (Mowanjum Sand) and its alluvial fan aprons, local Holocene white sand dunes, interfingering of red desert sand and white coastal dune sand, white dune and cemented white dune lenses in the red sand; represents the sea-cliffed margin of the red desert sand exposed at the coast and its stratigraphic products along the Canning Coast (Semeniuk 2008)</td>
</tr>
<tr>
<td>Location</td>
<td>Basin</td>
<td>Climate</td>
<td>Coastal Features</td>
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<tr>
<td>Eighty Mile Beach</td>
<td>Canning Basin</td>
<td>Tropical, arid;</td>
<td>Barrier of sand with leeward high-tidal flats, coquina on beach face, extensive</td>
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<td></td>
<td></td>
<td>macrotidal and</td>
<td>low-tidal flats; represents the barrier and associated leeward supratidal to</td>
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<td></td>
<td></td>
<td>wave-dominated</td>
<td>high-tidal plain and flats of a retreating coast of the Canning Coast (Semeniuk</td>
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<td></td>
<td></td>
<td></td>
<td>2008)</td>
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<tr>
<td>Pilbara Coast focused on</td>
<td>Pilbara Region</td>
<td>Tropical, arid;</td>
<td>At the largest scale, there are several megascale coats: 1. limestone barrier</td>
</tr>
<tr>
<td>Finucane Island at Port Hedland</td>
<td></td>
<td>macrotidal grading</td>
<td>islands and their leeward tidal flats, 2. active deltas, and inactive eroding</td>
</tr>
<tr>
<td>Point Samson, Cleaverville</td>
<td></td>
<td>to south to</td>
<td>deltas, 3. archipelago-ria shores, 4. beach/dune shores, and 5. embayment</td>
</tr>
<tr>
<td>Hearson Cove, King Bay</td>
<td></td>
<td>mesotidal, and</td>
<td>coats; at the smaller scales, a plethora of Precambrian, Pleistocene, and</td>
</tr>
<tr>
<td>Dampier Archipelago,</td>
<td></td>
<td>wave-dominated</td>
<td>Holocene lithologic and stratigraphic features; these include deltas (Maitland</td>
</tr>
<tr>
<td>Maitland River Delta,</td>
<td></td>
<td></td>
<td>River Delta), beach/dune systems (Onslow), ria embayment fills (Dampier</td>
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<tr>
<td>and Onslow</td>
<td></td>
<td></td>
<td>Archipelago), Pleistocene limestone lithology and stratigraphy (Finucane</td>
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<td></td>
<td></td>
<td></td>
<td>Island), modern rocky shores cut into Precambrian rock and Pleistocene</td>
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<td></td>
<td></td>
<td></td>
<td>limestone (Finucane Island, Cossack, Point Samson, Cleaverville, Dampier</td>
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<td></td>
<td>Archipelago, King Bay, Hearson Cove), beachrock (Dampier Archipelago,</td>
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<td></td>
<td></td>
<td>Hearson Cove), mangrove lithotopes (Dampier Archipelago), low-tidal mud</td>
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<td>flats and sand flats, bouldery shores (Dampier Archipelago), exposures at the</td>
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<td>coast of Precambrian lithologies and structures such as granite, gabbro,</td>
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<td>granite/gabbro contact, dolerite, xenolithic dolerite and gabbro (Dampier</td>
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<td></td>
<td>Archipelago, Hearson Cove), ironstone, chert (Cleaverville), isoclinal folds</td>
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<td>(Cossack, Point Samson), modern processes and products of coastal erosion (such</td>
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<td>as rocky shore benches and pavements, and cliffs, salt weathering); the more</td>
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<td>specific locations illustrate Pleistocene limestone stratigraphy,</td>
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<td>unconformity, and modern rocky shore features cut into limestone (Finucane</td>
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<td>Island), Precambrian greenstones (Cossack, Cleaverville, Point Samson),</td>
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<td>Pleistocene limestone as a lithified soil (Point Samson); igneous rock</td>
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<td>complexes, embayments and their sediments, styles of rocky shores, and</td>
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<td>bouldery shore (Hearson Cove, King Bay), an arid-zone delta (Maitland River</td>
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<td>Delta), and a limestone barrier system (Onslow); described in more detail by</td>
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<td></td>
<td>Semeniuk (1996)</td>
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<tr>
<td>Cape Range (Exmouth region)</td>
<td>Carnarvon Basin</td>
<td>Tropical, arid;</td>
<td>At the large scale, a cape of Tertiary and Quaternary limestones, cliffed at the</td>
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<td></td>
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<td>microtidal and</td>
<td>shore, traversed by consequent short creeks with limestone gravel channel-</td>
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<td></td>
<td></td>
<td>wave-dominated</td>
<td>fills, marine-cemented limestone gravel, and small deltas; locally there are</td>
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<td>shoreline dunes and mangrove-vegetated bays; cliffs expose Pleistocene coral</td>
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<td>reefs in limestone ridges parallel to the coast, and calcrite-cemented gravels;</td>
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<td>described in part by van de Graaf et al. (1976); an excellent outcrop of coral</td>
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<td>limestone is present at Yardie Creek</td>
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<tr>
<td>Location</td>
<td>Basin</td>
<td>Climate, tides, wave domination</td>
<td>Description</td>
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<tr>
<td>Gascoyne River Delta</td>
<td>Carnarvon Basin</td>
<td>Subtropical, arid; macrotidal and wave-dominated</td>
<td>Asymmetric lobate wave-dominated delta with internal features of beach ridges, strandplain, dunes, tidal flats, tidal creeks, and mangrove-vegetation lithotopes (Johnson 1982; Semeniuk 1986)</td>
</tr>
<tr>
<td>Shark Bay region</td>
<td>Carnarvon Basin</td>
<td>Subtropical, arid; macrotidal and wave-dominated</td>
<td>At the large scale, barrier peninsula (Edel Land) of Pleistocene limestone and a central peninsula (Peron Peninsula) of red sand, creating two major parallel NNW-trending elongated gulfs (Denham Sound and Freycinet embayment, and Eastern Gulf and Hamelin Bay), partitioned into oceanic, metahaline and hypersaline environments by transverse submarine barriers; the longitudinal shore is fringed by seagrass banks, sandy beaches, limestone and red-sand cliffed shores; tidal flats, oolite shoals and dunes, stromatolites, and coquina occur in hypersaline waters; at smaller scales there is a multitude of geological/geomorphological features, e.g., limestone cliffs, stratigraphy of Pleistocene red-sand and aeolianite, Pleistocene marine deposits, Pleistocene oolite, calcrete, beachrock, cemented crusts, spits; described by Logan (1970; 1973)</td>
</tr>
<tr>
<td>Murchison River estuary, Kalbarri</td>
<td>Carnarvon Basin</td>
<td>Subtropical, semi-arid; macrotidal and wave-dominated</td>
<td>At the large scale, the Murchison River has incised a deep meandering gorge into the Ordovician Tumblagooda Sandstone (Geological Survey of Western Australia 1990; Hocking 1991); this riverine system has formed a partially-barred estuary at its entrance to the sea</td>
</tr>
<tr>
<td>Kalbarri: Red Bluff</td>
<td>Carnarvon Basin</td>
<td>Subtropical, semi-arid; macrotidal and wave-dominated</td>
<td>Sea cliffs cut into the Ordovician Tumblagooda Sandstone, provide excellent exposure of fluvial and estuarine stratigraphy illustrating fluvial channels, cross-bedded sandstone, slumped cross-bedding, conglomerate, and estuarine facies of layered to burrowed sandstone, and channel deposits (Hocking 1991); the Tumblagooda Sandstone is capped by Pleistocene yellow sand and aeolian limestone</td>
</tr>
<tr>
<td>Point Leander, Dongara coast</td>
<td>Perth Basin</td>
<td>Subtropical, semi-arid; microtidal and wave-dominated</td>
<td>Rocky shore cut into Pleistocene coral reef limestone; see detailed case study of the Point Leaner, Dongara coastal geosite</td>
</tr>
<tr>
<td>Perth Metropolitan rocky coast, focused on Muderup Rocks, North Beach, Ocean Reef</td>
<td>Perth Basin</td>
<td>Subtropical, subhumid; microtidal and wave-dominated</td>
<td>Rocky shore cut into Pleistocene sequences of beach and aeolianite limestone, ad local Pleistocene rocky shores; see detailed case study of the Muderup coastal geosite; Muderup rocks and the limestone rocky shores described in detail by Semeniuk (1985)</td>
</tr>
<tr>
<td>Location</td>
<td>Basin</td>
<td>Climate/Geology</td>
<td>Description</td>
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<tr>
<td>Point Peron</td>
<td>Perth Basin</td>
<td>Subtropical, arid; microtidal and wave-dominated</td>
<td>At the large scale, tombolo of Holocene sand that has captured an offshore limestone reef/island to form Point Peron; the limestone at the Point is Pleistocene rocky shore first described by Fairbridge (1950), and comprises the classic bench, cliff, notch, and pavement of limestone rocky shores; local sites of beach rock; this area is described by Seddon (1972) and Searle <em>et al.</em> (1988)</td>
</tr>
<tr>
<td>Becher Point</td>
<td>Perth Basin</td>
<td>Subtropical, subhumid; microtidal and wave-dominated</td>
<td>At the large scale, a Holocene accretionary cuspatte foreland of shore-parallel beach ridges and low dunes with intervening linear inter-ridge swales (Searle <em>et al.</em> 1988; Semeniuk 1995); the swales have developed over the Holocene into wetlands (C A Semeniuk 2007); the area stands as a global model for cuspatte foreland sedimentation and stratigraphy (Semeniuk *et al.*1988), for wetland development (C A Semeniuk 2007), and for diagenesis and calcrete development (Semeniuk 1985; Semeniuk &amp; C A Semeniuk 2000)</td>
</tr>
<tr>
<td>Yalgorup National Park, focused on Preston Beach</td>
<td>Perth Basin</td>
<td>Subtropical, subhumid; microtidal and wave-dominated</td>
<td>At the large scale, a coastal barrier with a stratigraphy that records sea level history in a bathymetrically complex coast; type section for the Preston Beach Coquina; described by (Semeniuk 1995; 1996)</td>
</tr>
<tr>
<td>Leschenault Peninsula and its leeward estuary</td>
<td>Perth Basin</td>
<td>Subtropical, subhumid; microtidal and wave-dominated</td>
<td>Holocene barrier dune with a leeward estuarine lagoon; plethora of smaller scale features such as parabolic dunes, calcrete, tidal zone permineralisation; calcrete breccia float-stone; see detailed case study of a Leschenault Peninsula coastal geopark</td>
</tr>
<tr>
<td>South Bunbury coast</td>
<td>Perth Basin</td>
<td>Subtropical, subhumid; microtidal and wave-dominated</td>
<td>A local coastal outcrop of Bunbury Basalt (showing hexagonal jointing, mineral-filled vesicles, and deuteric alteration) which represents the most northerly outcrop of the Formation, with an nearby outcrop of Pleistocene limestone recording shoreline conglomerate of limestone gravel and basalt gravel</td>
</tr>
<tr>
<td>Geographe Bay</td>
<td>Perth Basin</td>
<td>Subtropical, humid; microtidal and wave-dominated</td>
<td>At the large scale, an estuarine system of low sandy barriers and estuarine lagoons, with complex accretionary geomorphology and sedimentology reflecting fluvial/estuarine accretion interacting with barrier dune development; described by Searle &amp; Semeniuk (1985)</td>
</tr>
<tr>
<td>Bunker Bay</td>
<td>Perth Basin</td>
<td>Subtropical, humid; microtidal and wave-dominated</td>
<td>Rocky shore cut into Precambrian rock unconformably overlain by Pleistocene limestone; the limestone is comprised of beach to aeolian facies; the limestone complex has been tectonically uplifted; cave deposits are exposed in the cliff face (Fairbridge &amp; Teichert 1952)</td>
</tr>
<tr>
<td>Location</td>
<td>Physiographic Province</td>
<td>Climate</td>
<td>Geology</td>
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<tr>
<td>Leeuwin Coast between Cape Naturaliste and Cape Leeuwin</td>
<td>Leeuwin-Naturaliste Orogen</td>
<td>Subtropical, humid; microtidal and wave-dominated</td>
<td>At the large scale, a ridge of Precambrian rock capped and flanked by Pleistocene limestone and Holocene dunes; the Precambrian rocks are wave-washed and show excellent exposure of gneissic layering, granite, xenoliths in granite, and mylonites; details of the geology is in Myers (20xx)</td>
</tr>
<tr>
<td>D’Entrecasteaux coast</td>
<td>Southern exposure of the Perth Basin</td>
<td>Subtropical, humid; microtidal and wave-dominated</td>
<td>At the large scale, coastal zone of beaches, Holocene barrier dunes, Pleistocene limestone and Holocene dunes, small estuaries barred by the dune barriers</td>
</tr>
<tr>
<td>Black Point</td>
<td>Southernmost outcrop of Bunbury Basalt along the southern exposure of the Perth Basin</td>
<td>Subtropical, humid; microtidal and wave-dominated</td>
<td>At the large scale, rugged high-cliffed coast comprised of a headland jutting out 1.5 km from the main trend of the coast, exposing columnar-jointed Bunbury Basalt; this is the most southernmost outcrop of Bunbury Basalt in Western Australia in wave-washed cliffs exposes structures in the basalt, its surficial weathering, and overlying Quaternary stratigraphic units; this outcrop is the exposure of basalt in a Mesozoic valley-fill stratigraphic situation (Geological Survey of Western Australia 1990)</td>
</tr>
<tr>
<td>Broke Inlet</td>
<td>Albany-Fraser Orogen and Bremer Basin</td>
<td>Subtropical to near-Temperate, humid; microtidal and wave-dominated</td>
<td>An estuary located along the coastal fringe of a Precambrian rock massif (Albany-Fraser Orogen); the estuary is partially-barred by a barrier of Quaternary dunes; the estuary is elongate and shore-parallel behind its barrier dune; there are intra-estuarine deltas, formed where the rivers draining the hinterland have deposited sediment where they have met the protected lagoon; and the Quaternary barrier dunes have surface features of parabolic dunes oriented SW-NE; the system is described in Semeniuk et al. (2011).</td>
</tr>
<tr>
<td>Conspicuous Cliffs</td>
<td>Albany-Fraser Orogen and Bremer Basin</td>
<td>Subtropical to near-Temperate, humid; microtidal and wave-dominated</td>
<td>Large cliff exhibiting Pleistocene yellow sand stratigraphy and history of arid-zone aeolian sedimentation; the cliff is described in Semeniuk et al. (2011)</td>
</tr>
<tr>
<td>Walpole-Nornalup Inlet</td>
<td>Albany-Fraser Orogen and Bremer Basin</td>
<td>Subtropical to near-Temperate, humid; microtidal and wave-dominated</td>
<td>Twin ria estuarine embayment comprised of beaches, estuarine sand flats, cliffed shores, intra-estuarine deltas, beach ridges, wave-washed Precambrian rocks; see detailed case study of the Walpole-Nornalup coastal geopark</td>
</tr>
<tr>
<td>Denmark coast, focused on the rocky shores and Irwin Inlet</td>
<td>Albany-Fraser Orogen and Bremer Basin</td>
<td>Subtropical to near-Temperate, humid; microtidal and wave-dominated</td>
<td>At the large scale, Precambrian rocky headlands and barrier dunes with wave-washed granites and a variety of granitic and mafic gneisses; Irwin Inlet is part of a unique estuarine complex in south Western Australia with an estuary that once was as large as Broke Inlet (see above) but has been segmented into Irwin Inlet and an abandoned (stranded) estuary that is now a freshwater lake; Irwin Inlet is described in more detail in Semeniuk et al (2011)</td>
</tr>
<tr>
<td>Location</td>
<td>Geographical Setting</td>
<td>Climate</td>
<td>Description</td>
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<tr>
<td>Albany coast focused on rocky shores, tidal flats, Lake Sepping, and tombolos</td>
<td>Albany-Fraser Orogen and Bremer Basin</td>
<td>Subtropical to near-Temperate, humid; microtidal and wave-dominated</td>
<td>At the large scale, Precambrian rocky headlands and barrier dunes with wave-washed Precambrian granites, granitoids, xenolith-bearing granitoids, a variety of granitic and mafic gneisses, and mylonites; coast comprises exhumed landforms with granitic/gneissic rock monadnocks/inselbergs forming the mainland, and marine-erosion-exposed monadnocks/inselbergs forming coastal headlands and local islands; the islands have been sites of tombolo formation; locally, tombolo formation has formed embayments and (where barred) freshwater lakes; low-gradient tidal flats occur along the shores of some embayments.</td>
</tr>
<tr>
<td>Bremer Bay</td>
<td>Albany-Fraser Orogen and Bremer Basin</td>
<td>Subtropical to near-Temperate, semi-arid; microtidal and wave-dominated</td>
<td>At the large scale, Precambrian granite/gneiss rocky headlands and barrier dunes with wave-washed Precambrian rocks that are exhumed monadnocks/inselbergs with intervening areas of Tertiary sedimentary rock (Plantagenet Beds) and dune barriers; the Tertiary Beds locally form cliffs but mostly comprise a low-relief plateau bordering the coast; small rivers/creeks enter the sea forming small estuaries but also locally are impounded by dune barriers; at the coast there also are Pleistocene coastal limestones, and a series of Holocene inland-ingressing coastal dunes, the latter with wetlands (dune slacks, impounded creeks, and aeolian-excavated exposures of groundwater; the coast and wetlands are described by C A Semeniuk &amp; Semeniuk (2011a).</td>
</tr>
<tr>
<td>Esperance coast</td>
<td>Albany-Fraser Orogen and Bremer Basin</td>
<td>Subtropical to near-Temperate, semi-arid; microtidal and wave-dominated</td>
<td>At the large scale, Precambrian rocky headlands and barrier dunes with wave-washed Precambrian granites and gneisses; the coast comprises exhumed landforms with granitic/gneissic rock monadnocks/inselbergs surrounded and onlapped by Tertiary Plantagenet Beds forming the mainland, and marine-erosion-exposed monadnocks/inselbergs forming local near-shore islands (the Recherche Archipelago), and coastal headlands.</td>
</tr>
<tr>
<td>Bilbunya Dunes region</td>
<td>Eucla Basin</td>
<td>Subtropical to near-Temperate, semi-arid; microtidal and wave-dominated</td>
<td>At the large scale, a series of low-relief shore-parallel sandy barriers with intervening mud-filled lagoons and, to the east, a large erg of coastal dune sand with star dune and barchan dunes with associated wetlands as dune slacks; dune and wetlands described by C A Semeniuk &amp; Semeniuk (2011a).</td>
</tr>
<tr>
<td>Baxter Cliffs</td>
<td>Eucla Basin</td>
<td>Subtropical to near-Temperate, semi-arid; microtidal and wave-dominated</td>
<td>At the large scale, cliff coast bordering Nullarbor Plain, cut into Tertiary limestones that underlie the Plain; cliffs are 30-50 m high and expose stratigraphy of Tertiary limestone, Quaternary-age caves and cave-fills, and are bordered at their base by talus of cliff collapse narrow aprons of tidal rock platforms; cliffs are also site for type sections of Toolinna Limestone, Wilson Bluff Limestone, and Abrakurrie Limestone; limestone cliffs described in more detail in Lowry (1970) and Survey of Western Australia (1990).</td>
</tr>
<tr>
<td>Eyre coast</td>
<td>Eucla Basin</td>
<td>Subtropical to near-Temperate, semi-arid; microtidal and wave-dominated</td>
<td>At the large scale, in plan, a megascale coast-parallel deposit of sand and Quaternary limestone that have accreted from the Tertiary limestone cliff of the Eucla Basin and protrudes as a low-amplitude deposit to seawards; internally, the bulk of the system is comprised of low-relief shore-parallel limestone and sand ridges, parabolic dunes, both fixed by sparse vegetation; lithologies are composed dominantly of fine quartz sand and weakly-indurated limestone; along the coast there are pockets of beach ridges and active locally near the coast, the deposit of sand is mobile and forms transverse dunes and barchan dunes</td>
</tr>
</tbody>
</table>
Chapter 6: A hierarchical approach to classifying coastal types as a basis for identifying sites of geoheritage significance

Identifying, comparing, and assessing sites of coastal geoheritage significance begins with classifying coastal geology and geomorphology. However, the coastal zone is one of the most difficult environments to classify into natural groups for purposes of assigning geoheritage significance and undertaking geoconservation, for a number of reasons: 1. coasts can be complex, spanning geology, geomorphology, sedimentology, biogenesis, and diagenesis and, as such, coastal features can be viewed from a wide variety of geological perspectives; 2. there are features that are specifically formed at the coast that are not part of natural gradations or groupings (e.g., diagenetic products cannot be grouped with gradational coastal products of meso-geomorphology and micro-geomorphology); 3. good exposures of geological sequences of geoheritage significance in natural cliffs are ad hoc products of coastal erosion and not part of a coastal gradation or coastal system; and 4. there are various scales at which geological features are evident.

Coasts have been classified previously from a number of scientific perspectives and purposes and at different specific scales, and using a variety of approaches. Such classifications have resulted in an understanding of coastal forms or coastal evolution at global scale down to local scale, in models of sedimentation and stratigraphy oriented towards geohistory and/or resource exploration, in developing a framework for habitats, and in rational environmental management of the coastal zone. As such, there is a large body of literature dealing with categorisation of coastal forms based on their morphology, origin, evolution, and tectonic, oceanographic, or climatic setting (Johnson 1919; Valentin 1952; Bloom 1965; King 1972; Shepard 1973; Davies 1980; Kelletat 1995; Woodroffe 2002; Schwartz 2005). However, the various classifications developed to date have not lent themselves to be directly applicable to issues of geoheritage and geoconservation. For instance, genetic classifications provide an understanding of coastal evolution, coastal development, or coastal types but have not been useful in comparative studies for geoheritage and geoconservation in that they tend to be process-oriented (Brocx & Semeniuk 2007; Brocx 2008).

However, classifying coasts for this purpose is made difficult due to the complexity, intergradation, and different scales at which coastal features are expressed, with variation potentially present locally or regionally. While geological region and environmental setting play major roles in determining regional variation in coastal form and coastal products, or expression of geological content, coasts at the local scale commonly are expressions of a gradation of processes from (marine) inundation, to erosion, to deposition. Biogenic activity and diagenesis also play a role in forming coasts though they generally are subdominant to the other processes. To deal with this geodiversity, coasts are classified in the first instance by the products formed by the five processes discussed in Chapter 4. This addresses the Holocene expression of coasts. Coasts can also be of geoheritage significance because they illustrate ancient geohistorical sequences, or manifest Holocene history geomorphically and stratigraphically. This also addresses the geohistorical aspect of coasts.

While coastal classification systems abound, coasts have not been systematically classified for the purposes of recognising sites of geoheritage significance and for geoconservation. The reason for this is that geoheritage and geoconservation are relatively young endeavours compared to other established disciplines involved with the coast. For example, sedimentology is a long-established science (Wentworth 1922; Krumbein & Pettijohn 1938; Twenhofel 1939; Shrock 1948; Pettijohn 1949; Allen 1970), and sedimentologists have developed coastal classifications at regional scale (e.g. delta forms, barrier islands, amongst others), and an understanding of sedimentary sequences and sedimentary products at finer scales (Reineck & Singh 1980). Similarly, coastal geomorphologists have classified coasts (though occasionally somewhat differently to sedimentologists) generally at regional to large scales and, at a more detailed scale, rocky shore specialists have classified medium- and small-scale erosional features along coasts. All such classifications have been directed to the objective of the specialist science and (axiomatically) not in a manner to provide information directly to identify sites of geoheritage significance or for geoconservation, though their information is useful for comparative geoheritage/geoconservation usually at small scales of reference. Locally, where researchers have attempted to address geoheritage of coastal zones, they have applied existing terms and established classification(s) of smaller-scale geomorphic and sedimentological features. This has resulted in an inventory of coastal features (e.g., Kiernan 1997) rather than a classification for geoheritage purposes.
Whether it is species, ecosystems, or physical features, it is the differences (or diversity) in types of natural features, viz., biodiversity or geodiversity, as well as their rarity and representativeness that form the basis of selection of species, or of sites for conservation. Identification of coastal types, i.e., the “species of coasts”, and their geodiversity, should form the prelude to identifying sites of geoheritage significance. To this objective, this Thesis presents a classification of coastal types as the first step in identifying sites of geoheritage significance for geoconservation and coastal management. A hierarchical approach is presented here that identifies, in the first instance, “families” of coastal types, as a context and a prelude to identifying “species of coasts”.

Coasts initially can be categorised according to geological setting (e.g., Precambrian rock coast, Tertiary limestone coasts, Quaternary limestone coast), climatic setting (e.g., tropical; humid or tropical arid coasts), and oceanographic setting. Thereafter, coasts can be separated on the basis of forms developed by marine inundation, erosion, sedimentation, biogenesis, or diagenesis (as will be described later) and then, if necessary, subdivided into finer scales that result in recognition of further forms and patterns. There can be variation along the coast in terms of processes and products and development of coastal types, and these can be present at different scales within a region, and across regions. Also, many coastal localities around the world have classic exposures of type sections, reference sections, fossil occurrences, geological features such as large nodules and columnar jointing, and exposures illustrating Earth history (exposing geohistorical sequences). As a zone of interaction of sea, land, atmosphere and groundwater, for a given climate setting, it can also be a zone of distinct diagenesis (see later in section on ‘Types of coastal forms and/or geological features developed at the coast’).

Global coastal classifications – and their potential applicability to geoconservation

There have been a number of classifications published for coastal systems, as summarised and/or compiled by Kidson (1968), Shephard (1968), King (1972, 1982), Kelletat (1995), Woodroffe (2002), Fairbridge (2004), Finkl (2004), and Schwartz (2005). Classifications grade from over-arching and conceptual (e.g., Johnson 1919, Valentin 1952, Bloom 1965; Shephard 1973), to those focused on providing systematic global to regional environment-specific classifications based on an inventory of determinative processes (e.g., Coleman 1976; Reineck & Singh 1980 on delta forms; Fairbridge 1980 on estuaries; or Davies 1980 and Finkl 2004 on coasts globally), to those focused on regional to local details based on form and evolution (e.g., Guilcher 1953; Schwartz 1972, 1973; Klein 1976), wherein, for example, rocky shores, sandy shores, and muddy shores are recognised and described (as summarised by Woodroffe 2002), or where coastal types at finer scales are recognised (e.g., Semeniuk 1986a). Many authors have focused on the details of coasts to the extent that there has been subdivision (classification) of coasts determined by geology, climate, oceanographic setting, and tectonic setting. Rocky shores in particular provide a good example of this. They have been studied and classified into types based on local determinative environmental factors, lithology, form and evolution (Bird & Dent 1966; Edwards 1941; Emery & Foster 1956; Emery & Kuhn 1982; Guilcher 1953; Hills 1949; Stephenson 2000; Sunamura 1992; Trenhaile 1974, 1980, 1987, 1997; Wentworth 1938), and limestone rocky shores specifically have been subdivided into numerous types based on lithology and morphology responding to climate and oceanographic setting. As Finkl (2004) points out, over-arching classifications are broad in scope but lack specificity, while specialised studies are narrowly focused and provide uneven coverage of coastal taxonomic units.

From a global point of view, the classification of coasts has been approached from that involving tectonics (and later, plate tectonics), with the smaller-scale coastal features determined ultimately by their location in relation to tectonic plates, viz., as a collision coast or trailing coast (Inman & Nordstrom 1971; Haslett 2009), or that of submerging coasts, neutral coasts, and emerging coasts (Johnson 1919). They have also been categorised from a perspective of accretionary versus eroding coasts; and that of primary youthful coasts versus secondary coasts; amongst others. These classifications of coasts have been approached from the largest scale, as outlined above, to the smaller scales with classification of shore types based on response to waves, tides, climate, and rock types (see specific studies presented in King 1972; Schwartz 1972, 1973; Klein 1976).
A review of literature indicates that inventories of coastal features have been generated for purposes of geoheritage/geoconservation (e.g., Kiernan 1997), and coasts of geoheritage significance have been identified at specific locations on an ad hoc basis. These include, for example, a range of internationally- and nationally-significant coasts in the United Kingdom (cited in Soper 1984, Bennett 1989, and Sale et al. 1989), as well as locations in Australia such as those along the coast of Victoria, (see White et al. 2003), and at Hallett Cove in South Australia (see Parkin 1969; Drexel & Preiss 1995). However, a classification of coasts for the purposes of identifying features of geoheritage significance, to date, has not been systematically undertaken. As noted earlier, this is a difficult endeavour, for a number of reasons as will be outlined below.

Firstly, because of the reason of scale: large coastal tracts (i.e., megascale features) may be of geoheritage significance, especially from a global perspective (e.g., the ria shores of the Kimberley Coast of Western Australia), while at the other extreme, smaller-scale features, at crystal scale, also may be of geoheritage significance.

As discussed earlier in Chapter 2, scale should be a factor in developing a classification of sites for purposes of geoheritage and geoconservation in the coastal zone, because significant features along a given coast can be of various scales, from crystal size to terrane size, and both may be present in the same area (Brocx & Semeniuk 2007). Also, coastal features may be present at different scales (for example, deltas, or cliffs, or sandy spits, amongst many others; Semeniuk 1986a). However, most literature on coastal classification or on coastal evolution tends to deal with phenomena at one frame of reference but does not transcend scale.

Secondly, because of morphological and geological variability, coasts may be simple in form, lithology and structure, or they may be complex, or may be multi-genetic. Marine erosion, for instance, may result in a wide range of coastal types and complex coastal forms: at one extreme, coastal erosion may be incising into fairly uniform bedrock resulting in a range of differential responses dependant on the lithology (viz., relatively resistant such as granite, or relatively soft such as friable limestone), but if rock types are heterogeneously distributed, the eroding coast results in a heterogeneous suite of products and coastal forms. Marine erosion also may exhume landforms and geological features that were formerly buried: for example, a terrain of scattered granitoid/gneiss inselbergs, surrounded by younger, softer sedimentary materials, through marine transgression and erosion results in a headland-and-(sandy)-cove system where the marine-resistant inselbergs form large rounded headlands, and the areas of younger softer sedimentary materials, having eroded away, form the sandy coves.

Thirdly, coastal types commonly are intergradational, with gradational lineages often being multidimensional (with co-existing gradients, for instance, in wave energy, frequency of tidal inundation, groundwater salinity, sedimentary grainsizes, and lithologic composition), with differential responses and products related to these gradients, and this particularly renders classification complex. For instance, coasts grade from those wholly developed by marine inundation of the hinterland (with terrestrial forms still apparent) to eroded coasts with remnants of the original inundated morphology, to those dominated by erosional features, or a gradational suite of coasts ranging from recently-inundated hinterland to partly sediment-buried coasts to coasts wholly constructed by sedimentary processes.

Complications in developing a classification or applying a classification arise also because, depending on the scale of reference or observation, many features can be assigned to more than one category of coastal type.

Apart from some detailed work on rocky-shore types (Bird & Dent 1966; Edwards 1941; Emery & Foster 1956; Emery & Kuhn 1982; Guilcher 1953; Hills 1949; Stephenson 2000; Sunamura 1992; Trenhaile 1974, 1980, 1987, 1997; Wentworth 1938), classification of estuaries (Fairbridge 1980), depositional coasts such as beaches, coastal dunes, barriers, bars, and spits (Schwartz 1972; 1973, 2005) and tidal flats (Klein 1976; Reineck & Singh 1980; Semeniuk 1981b; 2005) which provide information on smaller-scale processes, products, and geodiversity, the classifications of coasts and coastal forms at the larger scale, cited above in the introduction to this sub-chapter on Global coastal
classifications, have not been useful for categorisation of sites of geoheritage significance. The classifications tend to be conceptual models developed to understand coastal setting and coastal evolution, and while they provide a framework for understanding the development of coasts, they are not product-oriented for smaller-scale features, and are not applicable for comparative geoheritage assessment at finer scales. For example, Davies (1980) provides a useful categorisation of coastal types based on integrating a range of features such as wave climate and tidal regime, distribution of shores types and climate, but the classification cannot be used at the site-specific scale for categorising and comparing the various aspects of geoheritage features.

A classification of coasts for purposes of identifying sites of geoheritage significance and for geoconservation has to: (1) be able to transcend a wide variety of coastal forms, from rocky shores and cliffs to depositional coasts, and their variety; (2) be able to encompass the variety of rocks types and materials presented at the shore; (3) deal with the variety of processes at the coast; and (4) also accommodate the variety of scales at which natural history features occur at the coast (i.e., features of geology, geomorphology, and geologically-relevant biogenesis). It must also address that fact that a given tract of coast may be of geoheritage significance for a number of different reasons: for features of crystal size, to small-scale geomorphic features, to diagenetic products, to large scale features of coastal form, or stratigraphy, or structure. None of the coastal classifications designed to date have been applicable in this manner.

**Proposed hierarchical approach to the categorisation of coasts**

To address the difficulty in applying existing genetic and non-genetic coastal classifications and coastal description that occur in a vast variety of geological settings, constructional to destructional settings, and in a large range of scales, a hierarchical approach to coastal classification is developed. This hierarchical approach can deal with coastal variability in terms of tectonic setting, rock types, erosional coasts, depositional coasts, and the plethora of classifications that occur at various scales of references because each of these variables is treated within a specific level of the hierarchical structure. As will be outlined below, there are three levels of treatment/description of a coast, with the hierarchical treatment essentially descending in scale.

The approach to coastal classification designed in this Thesis is based on the Western Australian coast, but if national and international comparisons are to be made for assessing geoheritage significance, it also needs to be consistently applicable comparatively to other parts of Australia, and globally. From this perspective, it is important to have a classification of coasts that can be used in a geoheritage context. Before the proposed classification/categorisation of coasts of eastern Australia is presented, a brief review of the adequacy of other coastal classifications is provided.

Coastal forms, with their variable geological content and geomorphic expression, are very different in various parts of the world and of course in various parts of Western Australia dependent on geological setting, history of the landforms, type of hinterland geomorphology, climate, oceanographic processes, and Quaternary coastal history. For instance, solely from a geological perspective, a sea cliff of geoheritage significance in the United Kingdom, portraying Mesozoic chalk stratigraphy, palaeontology and ichnology (The Chalk; Gallois 1965; Melville & Freshney 1982; Mortimore et al. 2001) has different attributes to the cliff cut into Mesozoic sandstone exposed in Western Australia (the Broome Sandstone; Brunnschweiler 1954, 1957; Veevers & Well 1961). Similarly, from a sedimentologic, climate and oceanographic perspective, mesotidal terrigenous mixed sand-and-mud tidal flat deposits in sub-arctic regions provide very different sets of processes, products and detailed structures from those in mesotidal carbonate-dominated or mixed sand-and-mud tidal flat deposits in tropical arid regions (Reineck & Singh 1980). For example, the mixed sand-and-mud tidal flats of Dampier Archipelago are different in tidal range, stratigraphy, small-scale products and sediment composition from carbonate-dominated tidal flats of the Canning Coast (Semeniuk & Wurm 1987; Semeniuk 2008). Similarly, coasts will respond to environmental settings developing different forms dependent on oceanography, tidal regimes, and climate. Thus, given the above examples, simply identifying a coastal form as a sea cliff or a tidal flat is insufficient to provide information for assessment and comparison for geoheritage and geoconservation purposes within a nation, and certainly internationally. Clearly, classification of coastal features and coasts needs to address the global and national variation in coastal features in their geological, climate, and oceanographic setting.
At the next level of scale, coasts develop various forms in response to the main coastal processes of marine inundation, erosion, sedimentation, biogenesis and diagenesis. These processes are instrumental in developing coastal forms and different types of coasts regardless of where the coast is located geologically, climatically or oceanographically. The coastal forms or coastal types generally will be ubiquitous and/or recurring, because the processes are ubiquitous.

Finally, there is a range a smaller-scale features of a coast that are particular and peculiar to a given location, because of the context of geological, climate and oceanographic setting, and the type of coast developed by the dominance or combinations of the processes of marine inundation, erosion, sedimentation, biogenesis, and diagenesis acting on the shore. For instance, for rocky shores, regardless of where they are developed, there may be palaeontological or ichnological (palaeo) biodiversity exposed on a shore platform in different parts of the world. There may region-specific large nodules/concretions of calcite, or phosphate, or iron/manganese, exposed on shore platforms. There may be petrified forests, or a range of sedimentary, igneous, deformational, or metamorphic structures well-exposed on wave-washed rocky shores in different geological regions in different parts of the state, nation or the world. Similarly, in the arena of modern sedimentology, there is variation globally (Reineck & Singh 1980): the fine scale sedimentary structures developed on a tropical arid tidal flat will contrast with those of boreal or arctic tidal flats (e.g., the latter may contain ice crystal prints). Thus the more detailed, or finer scale variation in coastal types will reflect the geological, climatic or oceanographic setting of the coast superimposed on the coastal types.

To address their state-wide, national and international variation, the proposed classification of coasts for purposes of assessing geoheritage significance and for geoconservation is approached in a three-level system (Figure 6.1.):

Level 1: geological region - identification of the setting of the coast, geologically, climatically, and oceanographically; geological setting and environmental setting will determine lithological range, structural orientation, and any significant geological content, as well as climate effects, wave and wind patterns, and tidal range; it will also determine the type of hinterland geomorphology that is presented to the coast, and provide an indication of regional coastal form; identification of geological regions and environmental setting in Western Australia translates to recognising major cratons and basins cropping out at the coast, and the climatic/oceanographic setting of a coastal tract;

Level 2: coastal type - identification/classification of the various coastal types developed by the processes of marine inundation, erosion, sedimentation, biogenesis, and diagenesis to provide consistent comparative information for coastal description and assessment within a given region, and to provide a framework for finer scale coastal features in a consistent context for describing, comparing and assessing sites of geoheritage significance; for Western Australia, twelve types of coasts are identified (see below); this level also identifies types of coasts of geoheritage significance;

Level 3: inventory of finer-scale coastal features – this is undertaken within the framework of coastal setting and coastal types identified by Levels 1 and 2, and provides data within the context of the twelve coastal types for comparative geoconservation purposes.

In this Thesis, categories of coastal features (generally the smaller coastal features of Level 3) or coastal types (of Level 2) are separated as a starting point to identifying sites that may have geoheritage significance, within a context of geological region and environmental setting (climate/oceanography) for developing a tool-kit for assessing sites of geoheritage significance to be developed in later Chapters.
In Western Australia, coasts are developed in different geological regions and different environmental settings, comprising latitudinally-varying climate and oceanography (Figure 5.1 and Brocx & Semeniuk 2010a). In the first instance, geological region is a major factor underpinning what form a coast will develop, in that it determines lithological range, structural orientation, and style of hinterland (i.e., hinterland geomorphology) and the rock types exposed at the coast. For instance, steeply dipping rocks striking normal to the coast will form peninsulae such as in Yampi Sound (Kimberley region) and Cleaverville (Pilbara Coast), while flat-lying sequences will form straight coasts and fretted coasts (Red Bluff, Kalbarri, and Baxter Cliffs, Nullarbor). Geological region also determines the tectonic and Holocene history of a region. Lithological sequences, and sedimentary, igneous, or metamorphic sequences in sea cliffs axiomatically will depend on the geological region being eroded, ranging, for example, from the interesting stratigraphy of an Ordovician fluvial to estuarine system (e.g., the Tumblagooda Sandstone at Red Bluff, Kalbarri) to Mesozoic fluvial to shallow marine systems (e.g., the Broome Sandstone at Gantheaume Point, Broome) to Precambrian igneous rock sequences in the Dampier Archipelago, to complexly folded Precambrian rocks in the King Leopold Mobile Zone of the south-western Kimberley region (with fold structures determining coastal orientation and coastal form), to complexly folded and faulted metamorphic rock sequences in the southern coast regions. In this context, the geological, climatic and oceanographic categorisation of a coast is, to some extent, scale-determined as geological, climate, and oceanographic regimes are subcontinental features.

In Western Australia there are eight geological regions that determine coastal form; these are the Kimberley region (comprised of the Kimberley Basin bordered by the Halls Creek Mobile Zone and King Leopold Mobile Zone, and flanked by Quaternary gulf s cut into the massif margins, viz., King Sound and Cambridge Gulf), the Canning Basin Region (Canning Coast), the Pilbara Region, the western Carnarvon Basin with its coastal ridges and gulf s reflecting a tectonically active horst-and-graben complex, and then progressing southwards through a variety of geological regions such as the Perth Basin, the Leeuwin Complex, the south coast between Augusta, Esperance, and Israelite Bay (cut in Precambrian rocks of the Albany-Fraser Orogen and Yilgarn Craton, and sediments of the Bremer Basin), and the eroding edge of the Eucla Basin.

Key aspects of the geology of these regions are summarised in Figure 5.1 and Table 6.1. The focus in Table 6.1 is on bedrock geology and not on Holocene coastal sediments and their geomorphic expression within a geological region, as the latter may be repetitive in form and content within the region. The focus is on the pre-Holocene geological character and geological setting as these will involve lithologies and large-scale structures that will determine large-scale to small-scale geomorphic expression along the coast, and the ranges of lithologies in the bedrock geology that may be exposed along wave-washed cliffs. Holocene coastal sediments within the one region can range from barriers with mobile parabolic dunes (e.g., in the Leschenault Peninsula of the Perth Basin Region), to beach ridges plains (e.g., in the Rockingham area of the Perth Basin Region), or to tidal flats (e.g., along the Pilbara Coast), and macrotidal beaches (e.g., along the Canning Coast) depending on coastal bathymetry, sediment type and supply, oceanographic and coastal processes, and climate.

Coastal form also is determined by the climatic setting in which coasts reside (Figure 5.1). Northern parts of Western Australia are tropical and subhumid, with high evaporation rates and enough rainfall to affect coastal margins via fresh-water seepage and run-off. The climate changes towards the south to tropical and subtropical arid, with high evaporation rates and minimal rainfall, to subtropical (nearly temperate) with moderate evaporation and high rainfall, and to subtropical arid along the south coast. Climate affects sea temperatures and has consequences on the solubility and production of shore limestones, carbonate grains, and carbonate precipitation (viz. skeletal production, limestone solubility, and diagenesis). The rainfall/evaporation ratio determines the amount of evaporation in the coastal zone, especially on tidal flats in macrotidal settings, and the amount of fresh water that is delivered to the coast zone in humid settings. Climate also determines whether the coast is wind-dominated, and determines wind patterns, wind directions, and strength, with its attendant effects on coastal dunes, wind waves, and evaporation, the extent that dunes are mobilised, and that rips and cusps are developed. In this context, the southern coast and the central western coast of Western Australia are wind-dominated.
Additionally, coastal form is determined by the oceanography in which coasts reside (Figure 5.1). Coasts may be extreme macrotidal, macrotidal, mesotidal, or microtidal (Davies 1980; Semeniuk 2005), and may be wave-dominated or tide-dominated, or protected. Northern parts of Western Australia are extreme macrotidal and macrotidal, and semidiurnal, and to some extent wave-dominated, with a maximum tidal range at King Sound, progressively decreasing northwards and southwards in the macrotidal tidal range between Port Hedland and the northern Kimberley area. Tidal range decreases to mesotidal and microtidal and semidiurnal towards the south, until along the southern coast it is microtidal and diurnal. The effect of oceanographic setting is the variation in the extent that wave action or tidal action develops coastal forms such as cliffs, or beach ridges, tidal creeks, rips, ridges-and-runnels, and cusps, amongst other products, and in the extent that shore platforms and benches along rocky shores are developed at various tidal levels. The oceanographic and wind climate regions are as follows: the region of the north-west coast of the Kimberley, the region of the Canning Coast and Pilbara Coast, the region of the Carnarvon Basin and northern Perth Basin Coast, the region of the southern Perth Basin Coast, and the region of the south coast facing the Southern Ocean.

The five coastal-forming processes described earlier in Chapter 4 can be operating on varying types of hinterland (i.e., hinterland geomorphology), and geological materials, e.g., marine inundation of a geologically complex high-relief dissected hinterland, or marine inundation of a relatively geologically simple high-relief dissected hinterland, or marine inundation of a geologically complex relatively low-relief dissected hinterland, and so on, with marine inundation dominant, or erosion dominant, or sedimentation dominant.

Table 6.1: Summary of the geology/lithology of the geological regions along the coast\(^1\)

<table>
<thead>
<tr>
<th>Region</th>
<th>Geology/Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kimberley</td>
<td>central massif region (Kimberley Basin) of flat-lying Proterozoic thickly interlayered sandstone, basalt, siltstone, and basic intrusive rock, and a tectonic mobile zone periphery or orogens (King Leopold Mobile Zone) of deformed and isoclinally folded igneous, metamorphic and sedimentary rock including greywacke, basalt, siltstone, acid volcanic rock, basic intrusive rock and granite</td>
</tr>
<tr>
<td>margin of Kimberley Region</td>
<td>the central Precambrian Kimberley rock massif is flanked by Quaternary gulfs of King Sound to the west and Cambridge Gulf to the east; these are developed along the margin of the massif; bedrock of the eastern gulf is usually lateritised Mesozoic sandstone of the Canning Basin</td>
</tr>
<tr>
<td>Canning Basin</td>
<td>Mesozoic sandstone with an abundance of diverse sedimentary structures; locally, there are overlying deposits of Tertiary sediments, Pleistocene calcarenites, and Pleistocene red sand</td>
</tr>
<tr>
<td>Pilbara</td>
<td>Precambrian granites, and folded to layered greenstones, cherts, and ironstones, and dolerites, volcanic rocks; coastal fringe of Pleistocene limestone, red sand, and conglomerate</td>
</tr>
<tr>
<td>Carnarvon Basin</td>
<td>largely horizontally layered Tertiary marine limestones, locally Silurian sandstone (with an abundance of diverse sedimentary structures), red to yellow quartz sand; Pleistocene limestone (seagrass facies, beach/dune facies, coral reefs, pedogenic materials, and rocky shore sequences)</td>
</tr>
<tr>
<td>Perth Basin</td>
<td>Pleistocene limestone (calcarenites) composed of seagrass facies, beach and dune sediments, rocky shore sequences, and coral reefs</td>
</tr>
<tr>
<td>Leeuwin Complex</td>
<td>granite, anorthosite gneiss and amphibolite strongly deformed (folded, faulted, and sheared) and recrystallised to granulite facies</td>
</tr>
<tr>
<td>Albany-Fraser Orogen / Bremer Basin / Yilgarn Craton</td>
<td>Yilgarn Craton in its southern region: massive granite and gneiss Albany-Fraser Orogen: folded amphibolite to greenschist facies of sedimentary protolith gneisses, migmatites and granites, with tectonic structures related to subduction processes and prolonged strike-slip tectonism (folded, faulted, and sheared); Bremer Basin: largely horizontally layered sandstone, siltstone, spongolite</td>
</tr>
<tr>
<td>Eucla Basin</td>
<td>horizontally layered bryozoan calcarenite, and locally developed shore-parallel aeolian deposits</td>
</tr>
</tbody>
</table>

1. Information from Geological Survey of Western Australia (1975, 1990), Playford et al. (1976), Myers (1994).
Level 2 - category-oriented classification of coastal types
developed by the five coast-forming processes

The category-oriented classification of coastal types presented here has been designed to classify the wide variety of coastal settings developed within the various geological regions described above. It has involved identifying the range of coastal forms (i.e., types of coasts, formed as products of the main end-member processes), capturing all forms of coasts at a high order level of classification, and provides a framework within which sites of geoheritage significance can be consistently compared and assessed. To relate the coastal features to a scalar frame of reference, scale descriptors are used thus ensuring that not only are coastal types and coastal features captured at all scales, but that similar coastal forms expressed at different scales also are captured.

It should be noted that in the classification to be developed there is a difference between coastal landform (such as a sea cliff with its various geomorphic attributes) and coastally-exposed geology in sea cliffs, otherwise a number of the types of coastal types to be described below may appear similar. For example, the sea cliffs cut into granite at Walpole (Semeniuk et al. 2011) are significant geomorphic entities, but they are cut into relatively uniform rocks and their geomorphic feature is the highlight. Where coasts are lithologically complicated they may express various geomorphic features such as stepping, terracing, and structural benches and, depending on lithology, at the small scale may exhibit tafoni, micro-pinnacles (lapiés), etched surfaces, or smoothed surfaces (Guilcher 1953; Trenhaile 1980, 1987; Semeniuk & Johnson 1985; Paskoff 2005). Thus, strictly from a geomorphic perspective, lithologically simple or lithologically complex coasts can manifest types of macroscale to microscale landforms (geomorphology) in response to their coastal setting. In contrast, many sea cliffs in addition to being geomorphic entities can have excellent exposures of geological features and, as such, they have a geological (geohistorical) importance. Similarly, in the sedimentary arena, a prograding coast can develop as beach ridges or as stranded tidal flats, both of which are strictly geomorphic features. However, the stratigraphy under the beach ridges or stranded tidal flats may comprise diagnostic and/or important sedimentary sequences, and records of sedimentation patterns, ocean history, climate changes, and sea level history. In this context, the beach ridges or stranded tidal flats, from a perspective of geoheritage significance, can function concurrently in three ways – as examples of coastal geomorphology, as examples of sequences recording sedimentary history, and as records of ocean history, climate changes, and sea level history.

Types of coastal types and/or geological features developed at the coast

Given the main formative processes (coastal inundation, erosion, sedimentation, biogenesis and diagenesis), and their combinations outlined above, and the geohistory that may be manifest within coastal features, for identifying sites of geoheritage significance and for geoconservation, broadly, there are twelve types of coastal forms and/or geological features developed in the coastal zone; these are:

Type 1: landforms developed by the post-glacial marine inundation of pre-existing landforms (the primary pre-inundated landscape is still evident);

Type 2: landforms developed by marine inundation of pre-existing landforms and coastal erosion of the bedrock geology, or hinterland landforms;

Type 3: landforms wholly developed by coastal erosion, or where erosion has totally or nearly totally overprinted primary (pre-transgression) hinterland landforms;

Type 4: coasts developed by the exhumation or isolation of older landforms and their geological features;

Type 5: coastal landforms developed by marine inundation and sedimentary infilling;

Type 6: landforms wholly constructed by coastal sedimentary processes that have been active during the Holocene;

Type 7: landforms constructed by Holocene coastal sedimentary processes that have superimposed erosional features;

Type 8: biogenic coasts;

Type 9: coasts with dominant or conspicuous diagenetic features;
Type 10: erosional coasts recording Holocene sea-level history;
Type 11: Holocene depositional coasts recording sedimentary history, ocean history, climate history and sea-level history; and
Type 12: sea cliffs specifically exposing key geological features such as lithology, stratigraphic sequences and contacts, and structure rather than just manifesting geomorphological features.

These coastal types are summarised diagrammatically in Figures 6.2 and oblique and vertical aerial photographic and on-site photographic examples are illustrated in Figures 6.4-6.6.

The coastal types are placed in groups showing the inter-relationships and intergradation between them (Figure 6.7). Figure 6.7 specifically also shows that after inundation, coastal types 1-7 are morphological stages with a trend towards increasing erosion on one hand, or a trend to increasing sedimentation on the other. Being intergradational, they are placed in a quasi-chronological order specifically to show their evolutionary stages following a marine transgression, and to show the sequence from erosion-dominant coasts to sedimentation-dominant coasts. Type 9 involves specific features developed by diagenesis. For all these coastal types there will be variation in scale of the geological/geomorphological feature. Types 10, 11, 12 and, in part, Type 8 are special categories that manifest geological features useful to determining pre-Holocene Earth history, or sedimentary history, ocean history, climate history or sea-level history during the Holocene.

Types 1 and 2 overlap to some degree, but generally Type 1 is developed at the larger scale (e.g., rias of the Kimberley Region). Type 3, though expressed as large-scale features (such as sea cliffs along the edge of the Nullarbor Plain, or the Zuytdorp Cliffs; Figure 6.4E), is best expressed at the fine to small scale (e.g., benches along rocky shores). In many locations, Types 1, 2 and 3 are separated, because, although often co-existing in the same region, they represent stages in coastal development from primary to fully eroded, and the types may be present at different scales within the same tract of coast. Types 1, 2 and 5 also are inter-related: marine inundation and erosion of bedrock along the coast can develop sedimentary accumulations that are linked to the pre-existing topography, and these sediments partly fill the embayments of Coast Type 1 (cf. Semeniuk 1985b), or there may be development of cuspate forelands, or tombolos that capture eroding nearshore rocky islands. Types 5 and 6 overlap, reflecting increasing erosion of Holocene sedimentary materials.

As a product of the interaction of seawater, fresh water, evaporation and chemical reactions along the shore zone, Type 9, with fine- to small-scale diagenetic features, can occur in any of the other coastal types. On the other hand, it can also form a shore type in isolation (e.g., beach-rock coasts where beach rock forms thick cemented deposits that dominate the shore).

There may be partitioning of some of the coastal types listed above across a shore. This is particularly the case for coasts with diagenetic features and biogenic features. That is, a given shore may have tidally-related zones of diagenesis or biogenic construction, e.g., a sea cliff (Type 12), or a beach/dune system (Type 7), may have a coral reef expressed along its low-tidal zone, or a zone of distinct diagenesis, respectively.

Type 12 is a special category of coast where erosion has particularly emphasised the lithological, structural and stratigraphic features of the local pre-Holocene geology. The rock types can range in age from Precambrian to Pleistocene.

In the above examples, there is emphasis on products, but there are extant processes that are still generating these products. What constitutes “dynamic processes” has been discussed earlier in Chapter 2 (Modern landscapes where actives processes are operating), encompassing those that are very active and conspicuously dynamic (such as ingressing mobile dunes, collapsing sea cliffs), to the slowly retreating cliffs, to slowly advancing coasts, to slow-acting chemical and bioerosion that nonetheless control and develop the small-scale and fine-scale geomorphic features at the coast. Regardless of rate and scale of process operating, it is the coastal process (or processes) in action that constitutes a dynamic environment.
Because coasts are complex from a geoheritage perspective, a tract of coast can be assigned to a number of categories of coastal type, and assignment to one category does not mean exclusion from another. For instance, the Baxter Cliffs along the Nullarbor Plains can be assigned geomorphologically as an “eroding coast”, and to the category of reference stratigraphic site or type section (Type 12) for the Toolinna Limestone at Toolinna Cove, as well as to the category that comprises fine- to small-scale diagenetic features formed along the coastal zone (in the development of a cemented rocky shore platform in this particular climatic and hydrological setting). Similarly, the Point Becher area can be assigned to the category of “landforms constructed by Holocene sedimentary coastal processes” (i.e., the accreting beach ridge plains, the coastal chaots, and the local ingressing parabolic dune; see Semeniuk et al. 1988; C A Semeniuk 2007), as well as to that of “depositional coasts recording sedimentary history, ocean history, climate history and sea-level history” (i.e., the stratigraphy under the beach-ridge plain records sea-level history, ocean history, and climate history).

As mentioned earlier in this Chapter, for many of the types of coast, a given coastal feature can occur at different scales. The classification of coastal types, therefore, has been presented as non-scalar, and the identification of a coastal type or coastal features is not fixed to a given scale. In this context, coastal features identified and classified as to type can be related to a scale by a (geomorphic) descriptor (viz., megascale, macroscale, mesoscale, microscale, leptoscale, or other size-equivalent terms). Spits and rocky shores are used to illustrate coastal feature (or a coastal type) occurring at various scales (Figure 6.8).

Some coastal forms can be developed by erosion during a number of repetitive Quaternary transgressions, of which the current Holocene marine inundation (axiomatically) is the last in a series of such episodes. Hence, at the megascale and macroscale, coastal forms developed by erosion may be reflecting a number of Quaternary erosional episodes. This is most likely to develop where there has been marine inundation of dissected topography cut into hard rocks to develop ria shores, and hence the current ria form also is the Pleistocene form. Nonetheless, the Holocene transgression has inundated a Pleistocene topography, some of which may have been developed by Pleistocene coastal processes. With softer rocks, where erosion is rapid (e.g., eroding limestones to form the Twelve Apostles in Victoria, and the Baxter Cliffs in southern Western Australia, and coastal Pleistocene limestone in southwestern Australia), this is not an issue because Holocene erosion actually is the determining factor in developing the coastal form.

To illustrate the principles involved and to illustrate the variability of form and content of coasts, descriptions of some of these coastal types are provided below, largely drawn from Western Australian examples, but supplemented by other Australian and by international examples. In the descriptions that follow, the relationship of the types to the four categories of geoheritage of Brocx & Semeniuk (2007) is provided. Examples of coastal forms that are present within the twelve coastal types in Western Australia are provided in the description of each of the coastal types.

**Type 1: coastal landforms formed by marine inundation**

Coastal landforms developed by the post-glacial marine inundation of pre-existing terrestrial landforms, including those of Pleistocene age, vary from large-scale features to smaller-scale morphologic features. Examples from Western Australia of large-scale coastal landforms are the ria shores of the Kimberley Coast (which formed by the marine inundation of a fluvially-dissected terrain), the limestone barrier island complexes along the Pilbara Coast (Semeniuk 1996c), the complex coast of the Dampier Archipelago, and the gulf-and-peninsula morphology of Shark Bay. Examples of fine- to small-scale morphologic features are the inundated boulder slopes of the rocky islands of the Dampier Archipelago (Semeniuk et al. 1982), and some of the limestone barrier islands along the Pilbara Coast (Semeniuk 1996c), amongst others.

Coastal Type 1 can be assigned to the geoheritage category of modern, active landscapes in that coastal landforms developed by the post-glacial marine inundation of the landscape are extant.
Type 2: coastal landforms developed by marine inundation and coastal erosion

These are coastal landforms developed by the result of Holocene post-glacial marine inundation of pre-existing landforms and coastal erosion of the bedrock geology, or hinterland landforms. Marine inundation develops the primary coastal type, and erosion develops finer-scale features therein. The erosional products vary in size from large-scale (such as marine cliffs) to small-scale features such as shore platforms and benches, or micro-morphologic features (such as micro-pinnacles and tafoni). Variation in style and form of coasts result from differing bedrock materials such as granite, shale, folded metamorphic rock, or limestone (e.g., rounded shores, plunging cliffs, stepped platforms and benches, serrated platforms, or high tidal pavements cut into limestone by salt weathering), and the various coastal landforms developed by marine inundation of the pre-existing terrestrial landforms. Examples at the fine- to small-scale features are platforms, benches, notches and micro-pinnacles cut into calcarenites exposed along the shores of Rottnest Island and the Perth region (Semeniuk & Johnson 1985; Playford 1988), and the extensive high-tidal limestone pavements formed by salt weathering of Pleistocene limestone barriers in the Pilbara region (Semeniuk 1996c). The emphasis here is that coastal erosion has modified the morphology of the coast after the post-glacial marine inundation, resulting in varying coastal forms from medium scale to small and fine scale. Some of the complexity of products of erosion is the result of marine erosion acting on lithologically-layered or heterogeneous rocks (e.g., structural benches controlled by lithology such as horizontal shale beds, or horizontal, hard, sandstone beds). Some are due to the effects of marine planation and erosion, producing benches that are related to present and/or former Holocene sea-level positions, and modern climate setting and oceanographic setting.

Coastal Type 2 mostly can be assigned to the geoheritage category of modern, active landscapes in that coastal landforms developed by the post-glacial marine inundation of the landscape, and their erosion, are extant.

Type 3: landforms wholly developed by coastal erosion

These coastal landforms are wholly developed by erosion, or where erosion has totally or nearly totally overprinted primary (pre-transgression) hinterland forms. Sea cliffs are a common product of this type of coastal development, and these can vary from large scale, such as extensive and high sea cliffs, to smaller-scale cliffs, platforms and benches. At smaller scales along all scales of sea cliffs, there may be lithologically-determined structural benches and platforms, and benches, and platforms, smaller cliffs, and a variety of other fine-scale features (Semeniuk & Johnson 1985) determined by height of the shore relative to sea level in a given climatic/oceanographic setting.

Examples of this coastal landform are the modern crenulate-cliffed coast cut into Tertiary limestone along the edge of the Nullarbor Plain in Western Australia (e.g., the Baxter Cliffs), the modern retreating, crenulate, cliffed coast cut into Tertiary limestone in Victoria (The Twelve Apostles), and the smaller-scale cliffs, platforms and benches, along the seaward edge of limestone barriers of the Pilbara Coast (Semeniuk 1996c), such as at Finucane Island.

Coastal Type 3 can be assigned generally to the geoheritage category of modern, active landscapes.

Type 4: coasts formed by the exhuming or isolation of older landforms

These landforms have developed by coastal erosion, exhuming or isolating formerly buried landforms and other geological features. The coastal landform usually is derived by the exhuming of a relatively large geological feature, and should dominate the coast, not merely be part of a hard band or other more resistant layer or band within a sedimentary, metamorphic or igneous system. Examples are inselbergs, or volcanic plugs that are embedded in less durable materials and that, through coastal erosion, have been exhumed or isolated. Such landforms can vary from large scale (such as granitic or gneissic headlands) to small scale, such as resistant basaltic bodies (e.g., dykes, or valley fills). The emphasis here is that, following the post-glacial transgression, coastal erosion has removed more easily eroded material that formerly had enveloped a geological feature (or landform) on the hinterland, and has isolated that feature now making it a prominent coastal landform. The landform and its coastal morphology has not formed primarily as a result of marine inundation, as is the case for a ria coast, or formed as a result of erosion of a geologically relatively uniform system, as is the case...
of the sea cliff along the edge of the Nullarbor Plain, but as the result of the exposure by coastal erosion of a geologically harder "node". In Western Australia, examples of coasts formed by exhuming or isolation of older landforms are: 1. rounded coastal granitic headlands (formerly inselbergs, or monadnocks that were scattered and partly to fully buried by Tertiary sediments inland of the Esperance coast) now exposed by the erosion of the surrounding Tertiary sediments; and 2. the outcrops of Bunbury Basalt, south of Bunbury and at Black Point (along the D’Entrecasteaux Coast), showing basalt-filled valley tracts as exposed by the erosion of the enclosing Cainozoic sediments (Geological Survey of Western Australia 1990; Brocx & Semeniuk 2007; and Figure 6.4G).

Coastal Type 4 can be assigned to two geoheritage categories: 1. modern, active landscapes and; 2. geohistorical sites. Modern, active landscapes have been formed by the post-glacial marine inundation of the pre-transgression landscape and its subsequent erosion. Where such coastal landforms have been in existence since the early to middle Holocene, and are now largely relict from earlier Holocene time, they represent a coastal type that can be assigned to the geoheritage category of geohistorical sites where the history of the Earth can be reconstructed, or the processes within the Earth in the past can be reconstructed. However, more generally, though mostly an exhumed feature, these coastal types carry a degree of on-going processes such as erosion.

**Type 5: coasts developed by marine inundation and sedimentary infilling**

Coastal landforms developed by marine inundation of the bedrock geology, or hinterland landforms and sedimentary infilling of the inundated bays, gulfs, or lagoons may vary in size from large-scale (such as sediment-filled gulfs) to medium-scale features such as sediment-filled swales in Holocene-inundated Pleistocene limestone-barrier complexes. Coastal sediments filling inundated regions/areas can wholly fill or partially fill the marine embayments. Examples include the seagrass bank sediment-filled linear embayments that have shoaled to tidal levels in the Edel Land system of Shark Bay (e.g., Useless Inlet, Boat Haven Inlet, Depuch Inlet), the tidal-sediment, partially filling and fringing the gulf of King Sound, and the tidal-sediment fill between the barrier-island complex of Pleistocene limestone at Finucane Island (west of Port Hedland). The emphasis here is that coastal sedimentation has modified the morphology of the coast after the initial post-glacial marine inundation by sedimentary infill or partial infill, resulting in varying coastal forms from large scale to medium scale.

Some of the sedimentation in this type of coast is the result of marine erosion acting on the inundated coast. The Peron Peninsula at Shark Bay is an example (Figure 6.9): marine transgression after the last glacial period has inundated the ancestral “gulfs” of Shark Bay, leaving the large ridge of red sand as a peninsula, the large ridge of limestone as another peninsula, and coastal erosion has developed sandy shorelines, recurved spits, sand platforms, and (calcrete) breccia ribbons.

Coastal Type 5 can be assigned to two geoheritage categories: 1. modern, active landscapes; and 2. geohistorical sites. Modern, active landscapes are coastal landforms developed by the post-glacial marine inundation of the landscape, and their sedimentary infilling, if still on-going, is extant. Where Holocene sedimentation is now inactive, the coastal type can be assigned to the geoheritage category of geohistorical sites where the history of the Earth can be reconstructed, or the processes within the Earth in the past (in the Holocene) can be reconstructed.

**Type 6: landforms wholly constructed by Holocene coastal processes**

This type of coast comprises landforms wholly constructed by sedimentary coastal processes that have been active during the Holocene. This aspect of coastal type focuses on coastal landforms, not on sedimentary (stratigraphic) sequence. Examples at the large and medium scale include dune barriers, beach-ridge systems, beach/dune systems, estuarine sedimentary accumulations, and deltas, amongst others. These tend to be relatively permanent coastal landform features. Examples at the small scale include sand spits, coquina (shell) spits, emergent tidal deltas, ridge-and-runnel complexes, and beach cusps. Some of the smaller-scale rhythmic coastal features tend to be relatively short-term features (e.g., ridge-and-runnel complexes, and beach cusps), although for some coasts, because of local coastal morphology such as headlands flanking curved beaches, combined with prevailing wave and wind patterns, there may be a tendency for some rhythmic coastal forms to be recurring on a regular basis. Examples of significant large and medium scale coastal landforms in Western Australia wholly constructed by coastal processes include the coastal carbonate mud flats, sandy barriers, and earlier
Holocene barriers of the Canning Coast (Semeniuk 2008), the deltas and barriers of the Pilbara Coast (Semeniuk 1996c), the delta of the Gascoyne River (Johnson 1982), the twin cuspatate foreland of the Rockingham-Becher area, viz., at Becher Point (Searle et al. 1988), and the Leschenault Peninsula Barrier Dune system (Semeniuk 1985a).

Coastal Type 6 can be assigned to the geoheritage category of modern, active landscapes in that coastal landform development is extant.

**Type 7: landforms constructed by Holocene coastal sedimentary processes that have superimposed erosional features**

This type of coast comprises landforms constructed by Holocene sedimentary coastal processes but where there has been later erosion. Thus it comprises depositional landforms, with superimposed erosional landforms. This coastal type also focuses on coastal landforms, not on sedimentary (stratigraphic) sequences. Examples at the large and medium scale include tidal flats with tidal-creek erosion, dune barriers with an eroding seaward margin, and beach-ridge systems with an eroding seaward edge, amongst others. Examples in Western Australia of significant coastal landforms initially constructed by Holocene coastal processes but with subsequent superimposed erosion features include tidal creeks cut into tidal flats in King Sound, Roebuck Plains, and Port Hedland (Semeniuk 1981a, Semeniuk 2008), the eroding seaward edge of some deltas of the Pilbara Coast (Semeniuk 1996c), and the eroding tip of Point Becher of the Rockingham-Becher area (Semeniuk 1995a).

Coastal Type 7 can be assigned to the geoheritage category of modern, active landscapes in that coastal landform development is extant.

**Type 8: biogenic coasts**

Coasts can be built by biogenic processes. This refers to coasts that have developed hard-surface reefs (coral reefs, serpulid reefs, oyster reefs, stromatolitic reefs), and are not due to sedimentary deposits that merely have a skeletal component. In the latter situation, skeletons of organisms behave as sediment particles under the action of waves, tides, currents and wind: they are transported, sorted, build accumulations, and develop sedimentary structures. As such, though biogenic in origin, skeletal accumulations are treated as sediments in this Thesis. Biogenic coasts, on the other hand, are hard-surface accretionary deposits.

Biogenic coasts tend to range in scale from microscale to the mesoscale. They are locally developed in Western Australia, e.g., where oysters form thick crusts or reef-like accumulations on cliff shores (as in the Dampier Archipelago), or where coral reefs fringe shallow subtidal to low tidal rocks and rock platforms (e.g., Port Hedland tidal platforms). In Shark Bay, stromatolitic reefs form in the tidal zone (Logan et al. 1974), developing resistant structures fronting Hamelin Pool and prograding seawards (Fig. 6.6H). Biogenic coasts most commonly occur in combination with other coastal forms (Fig. 6.6H), i.e., as zones or patches or short sectors within erosional or sedimentary coasts, and only infrequently in Western Australia come to dominate the coast.

Coastal Type 8 can be assigned to the following two geoheritage categories: modern, active landscapes in that the processes and products are extant and, if stranded and fossil, as geohistorical sites where the history of the Earth can be reconstructed, or the processes within the Earth in the past can be reconstructed because there is an emphasis on the record of sedimentary history, ocean history, climate history and sea-level history. The elevated stromatolitic reefs of Shark Bay illustrate the use of these structures to infer former higher Holocene sea levels.

**Type 9: coasts with dominant or conspicuous diagenetic features**

Diagenesis involves precipitation, solution, or chemical/mineral reactions, and diagenetic features can be formed along the coastal zone by hydrochemical, biological, and physical processes, acting alone or in combination in response to the interactions of seawater, fresh water, and evaporation and transpiration gradients across the tidal zone. The products may be fine-scale and small-scale and isolated, but conspicuous, overprinting existing sediments and rocks and superimposed on any of the coast types described above, or can come to dominate the coast as medium-scale products, and locally, diagenites, as in massive beach-rock occurrences that form rocky shores (Figure 8 of Semeniuk 2008).
and in extensive cemented pavements and breccia pavements. Examples of diagenetic coasts include beach rock (Ginsburg 1953) and gypsum precipitates such as nodules, crystal rosettes, crusts, and crystals forming an interlocking resistant meshwork under hypersaline flats (cf. Logan 1974; Shinn 1983).

Diagenetic features and sequences of significance in Western Australia include those recorded by Logan (1974) in Shark Bay (viz., carbonate-cemented crusts, gypsum precipitates, beach rock), the diagenetic features of the Pilbara Coast (Semeniuk 1996c), and the beach rock of the Canning Coast (Semeniuk 2008). Figure 10 illustrates a beach rock ramp forming a seafront along the Canning Coast, a cemented upper beach surface from Shark Bay, carbonate crusts and breccia pavement from Shark Bay, a meshwork of gypsum rosettes from a supratidal flat in Shark Bay, and an aragonitic patina (crust) formed on beach rock in the tidal zone along the Canning Coast.

Coastal Type 9 can be assigned to the geoheritage category of modern, active landscapes in that the processes and products are extant.

**Type 10: erosional coasts recording sea-level history**

This is a special type of coast where specific detailed Earth history information can be obtained from geomorphic and sedimentary features expressed and preserved along the shore. Contrasting with accretionary coasts where sea-level history can be preserved (see below), erosional coasts, where there has been cutting of platforms or pavements in the intertidal zone, can record coastal history, and in particular sea-level history (again, with relative sea-level history being eustatic, or the result of tectonism). Rocky shore sedimentary deposits and biogenic imprints also may be preserved. In this type of coast, there is focus on environmentally-specific erosional features (that can be related to mean sea level, or a tidal level). This is exemplified by various platforms, benches, and pavements cut into calcarenite exposed at the coast along south-western Australia, along the Pilbara Coast, and along the Canning Coast. Examples of erosional coasts that have been used to reconstruct (eustatic or tectonic) sea-level history include rocky shores cut into calcarenite at Point Peron (Fairbridge 1950) and Rottnest Island (Playford 1988).

Coastal Type 10 can be assigned to the geoheritage category of geohistorical sites where the history of the Earth can be reconstructed, or the processes within the Earth in the past can be reconstructed because there is an emphasis on the record of sea-level history.

**Type 11: depositional coasts recording tectonic history, sedimentary history, ocean history, climate history and sea-level history**

This is another special coast type where specific Earth history information can be obtained from coastal sedimentary sequences. Sedimentary accumulations can record sedimentary history, oceanic history, climate history and sea-level history (a geohistorical record). For depositional coasts, this aspect of coastal type focuses on stratigraphy and the fine- to small-scale sedimentary sequences therein, and their use for reconstructing geohistory in the Holocene. Examples in Western Australia of coastal sedimentary packages that record sedimentary history, climate, sea-level history (with relative sea-level history being eustatic, or the result of tectonism), and ocean history are provided by the coastal deposits along the Canning Coast (Semeniuk 2008), the cuspate forelands of the Rockingham-Becher to Whitfords area (Semeniuk & Searle 1986; Searle et al. 1988), the Preston Beach area (Semeniuk 1996b), and the Leschenault Peninsula Barrier Dune system (Semeniuk 1985a). The sedimentary sequences containing the geohistorical records may not necessarily be large to the extent that they dominate the landform, as are the examples cited above, nonetheless they can still contain valuable information.

Coastal Type 11 can be assigned to the geoheritage category of geohistorical sites where the history of the Earth can be reconstructed, or the processes within the Earth in the past can be reconstructed because there is an emphasis on the record of sedimentary history, ocean history, climate history and sea-level history.
Type 12: sea cliffs exposing lithology, stratigraphy, contacts, and structures

Sea cliffs are recognised as special sites of potential geoheritage significance, providing exposure of stratigraphic sequences, igneous and metamorphic sequences and contacts and structures; types sections, reference sections, or culturally significant sites, i.e., significant features of bedrock are made more evident by coastal erosion and provide opportunity to study Earth history in detail. With such diverse reasons for their geoheritage significance, cliffs do not fall into the gradation of natural groups as do the other coasts, and are essentially an ad hoc allocation with an emphasis on geological content, not coastal geomorphology. While this coastal form is described as sea cliff, this landform can vary from vertical cliffs to steeply plunging shores. While sea cliffs may be part of Coastal Types 2 & 3, where the emphasis on their occurrence is geomorphological, the main feature for this Coastal Type is that marine erosion exposes critical geological content, which may be manifest in vertical cliffs or in the steeply plunging coastlines. In this context, Type 12 Coastal Type can be part of Coastal Type 2 & 3 but they are highlighted as a separate coastal type because of their specifically important geological content.

While similar geological features may be exposed in inland cliff faces, river banks, soil-covered hill sides, or local outcrops, commonly there are better and more extensively wave-washed natural exposures along the coast as a result of cliff erosion, washing by wave action, erosion by wave action, and salt weathering (Brocx & Semeniuk 2009a). This also is evident in the literature because some of the best and classic stratigraphic locations and geological features are manifest in sea cliffs: the Devonian sequences around the coast of Devonshire in south-western England (Rudwick 1985), the chalk cliffs of Beachy Head, Seaford Head and the Seven Sisters along southern England (Gallois 1965; Melville & Freshney 1982; Mortimore et al. 2001), the Old Red Sandstone along the Orkney Islands in Scotland, the unconformity at Siccar Point in Scotland (Barclay et al. 2005; Brocx & Semeniuk 2007), the wave-cut platform developed on steeply-dipping layered limestone along the Bay of St. Jean-de-Luz, France (Machatschek 1969), the unconformable contact between Precambrian rocks and Permian glacigene sediments at Hallett Cove in South Australia (Parkin 1969; Drexel & Preiss 1995), and the Miocene limestone in the Port Campbell area (The Twelve Apostles) in Victoria (Birch 2003). A review of texts dealing with nature reserves and coasts also shows that exposures of stratigraphic sequences and geological features are best manifest in sea cliffs (Bennett 1989; Blandin 1992; Goudie & Gardner 1985; Holmes 1966; Michel 1991; Sale et al. 1989; Snead 1982; Soper 1984).

Often sea-cliff exposures may expose extensive bedding-plane features along lithologically-determined structural benches not as well evident in inland outcrops. For instance, shales that are recessively weathering in inland outcrops and cliffs, may exhibit sedimentary and palaeontological features on the bedding plane as a result of marine erosion, thus exposing important aspects of lithology, sedimentary structures, and palaeontology.

Examples of cliffs of significance in Western Australia include: exposures of Precambrian igneous rock in the Dampier Archipelago (Figure 13 in Semeniuk 1986a), the granitoid/gabbro contact at Hearsons Cove (Figure 6.4 in Brocx 2008), Precambrian exposures at Sugarloaf Rock, Skippy Rock, Barge Bay and Ringbolt Bay along the Leeuwin-Naturaliste Ridge (Myers 1994), Precambrian granite with xenoliths of earlier granite, west of Esperance (Figure 18 in Myers 1997), the Ordovician Tumblagooda Sandstone at Red Bluff, Kalbarri (Figure 1C in Brocx & Semeniuk 2009a); the Mesozoic Broome Sandstone at Gantheaume Point and Entrance Point at Broome; exposure of columnar-jointed Bunbury Basalt at Black Point (Figure 41 in Playford et al. 1976); the Tertiary Toolinna Limestone, Wilson Bluff Limestone, and Abrakurrie Limestone along the edge of the Nullarbor Plain at Baxter Cliffs (Figure 70 in Geological Survey of Western Australia 1975, and Figure 4-19B in Geological Survey of Western Australia 1990), the Quaternary Tamala Limestone along the Zuytdorp Cliffs (Figure 36 in Geological Survey of Western Australia 1975); and Pleistocene aeolianite and soil sheets at Hamelin Bay, and Precambrian rock, an elevated Precambrian/Pleistocene unconformity, Pleistocene aeolianite, marine bands, shore platform, and exhumed karst at Bunker Bay (in Fairbridge & Teichert 1952).
Coastal Type 12 can be assigned to the following three geoheritage categories: *type locations for stratigraphy, fossils, and mineral sites*, including locations for teaching, research, and reference; *cultural sites* where classic locations have been described; and *geohistorical sites* where there are classic exposures in cliffs and outcrops where the history of the Earth can be reconstructed, or the processes within the Earth in the past can be reconstructed.

In Western Australia, stratigraphic type sections that are located and well-exposed as sea cliffs at the coast are: the Broome Sandstone at Gantheaume Point (Brunnschweiler 1954, 1957; Veevers & Wells 1961), the Toolinna Limestone at Toolinna Cove (Lowry 1968), the Peron Sandstone, at Cape Peron, Shark Bay (Logan et al. 1970), the Tamala Limestone at Zuytdorp Cliffs (Geological Survey of Western Australia 1975, amended from Tamala Eolianite of Logan et al. 1970), the Pleistocene Carbla Oolite at Goat Point (Logan et al. 1970; and Fig. 10H), and the Holocene Kennedy Cottage Limestone and Horsewater Soak Calcarenite along the shores of Willie Creek (Semeniuk 2008).

**Level 3 – fine-scale refinement of coastal types and coastal products**

Environment-specific features (*i.e.*, environment-diagnostic features) or small-scale features mentioned earlier in the review of coastal classifications are often the focus of determining the geoheritage significance of a given coastal site. These can include features of a sedimentary, diagenetic, igneous, metamorphic, or structural geological nature. For instance, the striating effects of Permian glaciation on Proterozoic rocks at Hallett Cove in South Australia (Figure 51 in Parkin 1969), the giant non-septarian concretions embedded in the Bencliff Grit of the Upper Jurassic Corallian Formation at Osmington, Dorset Coast, UK (Talbot 1973; West 2011b), the giant non-septarian concretions of Bowling Balls Beach in Miocene Galloway Formation in the Mendocino County, California, USA (Konigsmark 2005; Klein 2013; Anon 2014a), and the giant septarian concretions in Palaeocene shale of the Moeraki Formation of Moeraki Beach, Otago coast, New Zealand (Boles et al. 1985) are of geoheritage significance, but are relatively small and localised features. They stand on their own as sites of geoheritage significance for the important features they manifest and contain. Larger coastal features such as extensive coastal cliffs as exposed at Baxter Cliffs along the edge of the Nullarbor Plain, Zuytdorp Cliffs marking the western edge of the Shark Bay system, and Red Bluff at Kalbarri (Figure 3.3), or complex sedimentary environments (such as barrier and estuarine lagoon systems, *e.g.*, Leschenault Peninsula and Inlet; or the Shark Bay environment; Figures 3.3 & 6.9) while they can be significant at the large scale also contain a plethora of noteworthy features at small scales equivalent to the environment-specific features noted above.

However, small-scale features should only be rigorously assessed and compared as to their geoheritage significance when placed in their geological framework. For example, the giant concretions at Osmington and at Bowling Balls Beach superficially appear to be comparable as they share attributes of being large concretions (Figure 6.10) but, when placed in their geological context and larger-scale framework, there are differences: the former are calcite-cemented concretions superimposed on roughly-horizontal shallow-water marine and inter-tidal cross-bedded grit and sandstone (Talbot 1973; West 2011b), with cross-bedding preserved in the concretions; the latter are calcite-cemented concretions overprinting steeply-dipping flat-bedded and flat-laminated sandstone and shale (locally with contorted lamination) and with laminations and contortions preserved in the concretions (Konigsmark 2005; Klein 2013; Anon 2014a). The two locations are not comparable lithologically, palaeo-environmentally, and structurally, and are geologically significant in their own right. The large concretions of Moeraki Beach in New Zealand are different from those of Osmington and Bowling Balls Beach in that they are very large and spherical (up to 2 m), and are septarian nodules. The fine-grained material comprising the concretions is cemented by calcite, which also partly replaces the host rock. The concretions are embedded in structureless mudstone and, as the host rock is structureless, the nodules (apart from the septaria) also are structureless. The ‘septaria’ of the nodules are filled with brown and yellow calcite, but locally with rarer late-stage dolomite and quartz (Boles et al. 1985).

In the same way, while superficially appearing similar in that they comprise crystal meshes of gypsum, diagenetic gypsum occurring in high-tidal saline environments of King Sound (Semeniuk 1982) is not comparable to those occurring in high-tidal environments of Shark Bay (Logan 1974) – though the gypsum crystals form an interlocking mesh within the sediment in both locations, the sedimentary settings of King Sound and Shark Bay are totally different environmentally, stratigraphically, hydrologically, and hydrochemically (Logan 1974; Semeniuk 1982).
A third example of small scale features requiring geological setting as background in order to assess their geoheritage significance is afforded by isoclinally folded Precambrian rocks exposed along rocky shores in coastal Western Australia (Figure 6.11). Such rocks occur along coasts that have been cut into the King Leopold Orogen in north-western and northern Western Australia, the Pilbara Craton in north-western Australia, the Leeuwin Complex of the Pinjarra Orogen in Leeuwin-Naturaliste region of south-western Australia, and the Albany-Fraser Orogen of southern Western Australia. In each case, the scale and geometry of folding is one of decimetre-sized to metre-sized isoclinal folds. If small-scale folding and the style of folding are the essential and important features of the outcrops and occur in these different locations in different orogens and cratons, then small-scale isoclinal folding could be considered to be a common feature of coastal outcrops of Precambrian rock. However, each of these locations of folded rock belong to different geological regions (Figure 6.1) and are comprised of different lithologies, manifest differing microscale features, and are of different ages (concepts and terms for description of folded rocks are from Turner & Weiss 1963; Hobbs et al. 1976 and Davis & Reynolds 1996).

The folds in the King Leopold Orogen, where exposed along the coast, are in low grade (muscovite-bearing) metamorphic rocks of Proterozoic age and record the development of the orogen along the margin of the Kimberley Basin (Griffin & Myers 1988; Griffin & Grey 1990a, 1990b; Tyler et al. 2012). Generally, they are relatively simple folds with few structural complexities. Small-scale folds in the Pilbara Craton are in greenstone facies (the greenstones) of Archaean age in the Fortescue Group in the West Pilbara Supercrane (Hickman & van Kranendonk 2012), and are composed of volcanic rocks, ironstone, chert, and shale (Thorne & Trendall 2001). At the regional scale, the greenstones of the Pilbara Craton as a granite-greenstone terrane have characteristic dome-and-basin geometry, and are regarded as examples of different tectonic processes operating in the Archaean (vertical tectonics, or diapirism). Repeated shortening events in the Pilbara Craton are considered to have resulted in partitioning the geology into competent granite bodies with intervening greenstone belts, and developing the fold interference patterns and characteristic dome-and-basin geometry (Blewett 2001). Because the rocks in this region are polythiotic, and can be interlayered on the small scale, they often exhibit relatively complex folds in response to differential lithologic behaviour to shear, compression, shortening, and layer-slip (with structural complexities such as fanning slatey cleavage, axial-plane crumpling, axial-plane brecciation, boudinage, and limb attenuation and limb shear). The folds in the Leeuwin Complex of the Pinjarra Orogen are in Proterozoic age granulite facies occurring as granitic, anorthositic, and metagabbroic gneisses, and they record a complex development of the orogen as a collage of terranes that were accreted to the western margin of the Yilgarn Craton during the Proterozoic (Myers 1990a, 1994). These folds range from relatively simple forms with few structural complexities to those that illustrate multiple phases of deformation, strong deformation, and partial melting (Myers 1994). Small-scale folds in the Albany-Fraser Orogen (in the Proterozoic Normalup Complex) occur in rocks that are strongly deformed and metamorphosed to amphibolite and locally to amphibolitic granulite facies, recording the development of the orogen as a zone of crustal mobility either developed on an older orogen or as a result of crustal mobility during the Proterozoic (Myers 1990b); the folds range from relatively simple types with few structural complexities to complex folds showing a series of deformation events.

Each of these small-scale isoclinal folds from the different orogens and cratons manifests mesostructural and micro-structural, metamorphic features, and structural orientation(s) in relation to their geological setting and lithology that enable geologists to unravel the structural/metamorphic history of the region (Hobbs et al. 1976; Davis & Reynolds 1996), and each fold locality presents a different picture of structural and metamorphic evolution of the terrane in which they are embedded. Therefore, even though as a generic classification they all can be classified as coastally-exposed small-scale isoclinal folds, they are incomparable as features of geoheritage significance when viewed in the perspective of their lithology in relation to their geological setting. The geological setting therefore has a bearing as to the significance of the outcrop locality and as to the importance of the isoclinal folds at a coastal site in terms of their geoheritage significance.
Stratigraphic sequences and sedimentary structures on modern tidal flats are provided as a final example of the importance of geological setting in assessing the geoheritage significance of small scale features. For instance, in Western Australia, depending on their regional geological, oceanographic, and climatic setting, modern tidal flats can be terrigenous-sediment-dominated, mixed terrigenous/carbonate sedimentary systems, or carbonate-sediment-dominated (Semeniuk 1993, 1996c, 2008), and can be wholly muddy, mixed sand and mud systems, or wholly sandy (Logan 1970, 1974; Semeniuk 1981b, 1983, 1985b, 2008; Unno & Semeniuk 2009). As such, there can be a plethora of shoaling stratigraphic profiles reflecting setting, provenance, and local coastal patterns. Therefore, it is important to compare the stratigraphic sequence or sedimentary structure being assessed for its geoheritage significance within a context of similar geological setting.

At the next and finer scale, again depending on regional setting, provenance, coastal processes and differentiation of coastal types as related to Level 2 description of coastal setting, there can be a range of sedimentary structures developed on the tidal flats. This is exemplified by the range of sedimentary structures illustrated in Reineck & Singh (1980) of various tidal flats around the World located in different sedimentological, climatic, and oceanographic settings. The more common sedimentary surfaces developed on tidal flats in Western Australia determined from the literature (Semeniuk 1981b, 1986a, 2005; Semeniuk et al. 1982; Unno & Semeniuk 2008) include the following: 1. current-sheared mud surfaces, 2. burrow-pocked mud surfaces, 3. feeding-pellet-littered mud surfaces, 4. cracked (desiccated) mud surfaces, 5. salt-crusted mud surfaces, 6. carbonate-crust-cemented mud surfaces, 7. brecciated cemented crusts on mud surfaces, 8. breccia pavements, 9. silt ripples on clay surfaces, 10. wave-rippled sand on mud surfaces, 11. wave-rippled or current-rippled sand surfaces, 12. mega-rippled sand surfaces, 13. burrow-pocked sand surfaces, 14. pelleted sand surfaces, 15. feeding-excision-pocked sand surfaces, 16. shell pavements. The common sedimentary structures listed above show, using a coastal system that has been generally well-described globally, the level of descriptive detail can be and should be achieved at Level 3.

While there has been an emphasis above on the stratigraphy and sedimentary structures of modern tidal flats, the same rationale for comparison and assessment can be applied to the stratigraphy and small-scale sedimentary features of ancient tidal flat sequences. And further, in principle, the same rationale of listing an inventory of stratigraphic and small scale sedimentological features can be applied to other accretionary sedimentary systems such as beach-dune coasts, barrier dune coasts, deltaic coasts, and estuarine embayments.

From this perspective, for there to be a rigorous comparison and assessment of their geoheritage significance, it is important to place smaller-scale features in their geological context - that is, regionally (Level 1) for their lithological, structural, metamorphic, or stratigraphic setting or for their geomorphic/sedimentological setting, and/or, at the next level, to relate them to their coastal type (Level 2).

Small-scale features can be identified, described and comparatively assessed within the setting of the twelve coastal categories. For instance, an erosional (cliff) coast may be assigned geoheritage significance based on its local geology or bedrock outcrops, its representativeness, or on some local feature not found elsewhere, e.g., the Tertiary limestone exposed along the Baxter Cliffs in southern Western Australia stand separate to the unconformity exposed in the cliffs at Hallett Cove in South Australia, and to the Permo-Triassic sedimentary sequences exposed in cliffs along the southern and central coast of New South Wales, and to the sea cliffs cut into Cretaceous chalk in Sussex, southern England. While all these sites illustrate examples of sea cliffs, each provides its own level of international and national significance based on geological (and tectonic) setting, age of sedimentary sequence, stratigraphic sequence, and specific local (unique) feature.
The full extent of further subdivision of coastal types for assessing geoheritage significance in developing an inventory of coastal features particular to geological and environmental setting, will be dependent on the variability in geology (including tectonism), geomorphology, diagenesis, climate and oceanography that is manifest locally, and is outside the scope of this Thesis. However, while it is not intended here to identify every nuance of coastal variation globally in this Thesis, for the purposes of assessing geoheritage significance comparatively, the approach to fine scale subdivision of the main coastal types is provided below. Table 6.2 lists some of the finer scale features for selected coastal regions drawn from coastal Western Australia and from the literature.

An inventory of some key geological features for twelve selected coastal sites in Western Australia drawn from the study sites as listed in Figure 3.4 is presented in Table 6.3. Information from the approach of listing the smaller-scale geological features within the context of Geological Region (Level 1 classification) and Coast Types (Level 2) provides a basis for inter-regional to international comparison of coastal types for determining representativeness or the unique nature of a coast for purposes of assessing geoheritage significance and for geoconservation. For instance, although the Point Becher cuspate foreland and the Leschenault Peninsula barrier dunes are Coast Type 6, both occur in the Perth Basin Geological Region, they represent different styles of sedimentary accumulations, with very different sets of finer-scale coastal landforms and sedimentary structures. Again, for those coasts developed by modern sedimentation (Type 6 coasts), but from different coastal regions, Table 6.3 shows the contrasts between wave-dominated deltas: one in the Pilbara region (the Maitland River delta), the other in the Carnarvon Basin region (the Gascoyne River delta). Though wave dominated, one is macrotidal and the other microtidal, and there is a difference in the finer scale geomorphic and sedimentary features within them in terms of specific landforms developed, and smaller-scale sedimentary structures, which render them different.

The regional geological, climate and oceanographic setting of a coast will result in site-specific expressions of climate history (e.g., expressed in the sediments through fauna, microbiota, such as foraminifera, and diagenesis), history of storminess (e.g., as expressed in cheniers, and tempestites), mean sea level (MSL) history (as expressed in heights of stratigraphic interfaces, or sea-level specific landforms), amongst others. Table 6.3 also specifically shows the contrast in coastal products at the fine scale of the sea cliffs using a cliff cut into Silurian sandstone at Red Bluff and one cut into Mesozoic sandstone at Gantheaume Point.
Table 6.2: Examples of smaller-scale features occurring within Level 2 coastal type

<table>
<thead>
<tr>
<th>Level 2 coastal type</th>
<th>Potential finer scale features for a given coastal type, and next stage of coastal division</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1: landforms developed by inundation</td>
<td>identifying coasts such as ria, dendritic embayed forms, ridges-and-gulfs, or limestone barrier islands (i.e., all based on the inundated ancestral hinterland morphology)</td>
</tr>
<tr>
<td>Type 2: coast developed by inundation and erosion</td>
<td>identifying coasts as for Type 1, as to form, and then erosion features such as cliffs, talus, shore platforms and benches, notches, micro-pinnacles, tafoni, etched surfaces, and smoothed surfaces, and lithology-related variation in style of erosion, viz., rounded shores, plunging cliffs, stepped platforms and benches, serrated platforms, high tidal pavements in relationship to oceanographic and climate setting</td>
</tr>
<tr>
<td>Type 3: coast developed wholly by erosion</td>
<td>identifying erosional features such as cliffs, shore platforms and benches, notches, micro-pinnacles, tafoni, etched surfaces, and smoothed surfaces, lithology-related variation in style of erosion (rounded shores, plunging cliffs, stepped platforms and benches, serrated platforms, high tidal pavements) in relationship to oceanographic and climate setting</td>
</tr>
<tr>
<td>Type 4: coasts developed by exhumation of older landforms</td>
<td>isolated headlands, coastal knolls, cove-and-headland morphology, and the erosional products peripheral to the resistant landforms</td>
</tr>
<tr>
<td>Type 5: coast developed by inundation and sedimentation</td>
<td>identifying ria, dendritic embayed coasts, ridge-and-gulf morphology, or limestone barrier islands, and then depositional landforms such as barriers, spits, tidal flats, beach ridge plains, bay-head deltas, in relationship to oceanographic and climate setting</td>
</tr>
<tr>
<td>Type 6: coast constructed by sedimentation</td>
<td>barrier dunes, cuspate forelands, beach ridge plains, beach/dune coasts, deltas, prograded tidal flats</td>
</tr>
<tr>
<td>Type 7: coast constructed by sedimentation; superimposed erosion</td>
<td>tidal creek, or seafront erosion of deltas and prograded tidal flats; and eroding (cliffed) seafront of barrier dunes, cuspate forelands, and beach ridge plains, with both styles of erosion related to oceanographic and climate setting</td>
</tr>
<tr>
<td>Type 8: biogenic coasts</td>
<td>identifying coasts as bioherms or biostromes, and constructed by corals, oysters, mussels, stromatolites, serpulid worms, mainly in relationship to climate</td>
</tr>
<tr>
<td>Type 9: diagenetic coast</td>
<td>identifying whether coasts are comprised of beach rock, cemented pavements, gypsum pavement in relationship to oceanographic and climate settings</td>
</tr>
<tr>
<td>Type 10: erosional coasts recording Holocene history</td>
<td>identifying sea-level related erosional features, or elevated diagenetic and biogenetic features on the rocky shore</td>
</tr>
<tr>
<td>Type 11: depositional coasts recording Holocene history</td>
<td>identifying type of stratigraphy and biostratigraphy, and identification of sea-level, climate, and ocean-history features related to stratigraphy</td>
</tr>
<tr>
<td>Type 12: sea cliffs exhibiting lithology, and history</td>
<td>identifying the type of formation, and rock sequences, and rock features exposed by the sea cliff; rock features deriving from, and dependant on Level 1 setting</td>
</tr>
</tbody>
</table>
Table 6.3: Some examples of smaller-scale features occurring along selected sites of geoheritage significance along the Western Australian coast

<table>
<thead>
<tr>
<th>Location (Figure 3.4)</th>
<th>Geological, climatic, oceanographic setting</th>
<th>Coastal Type</th>
<th>Key smaller-scale features at the site of geoheritage significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willie Creek, north of Broome</td>
<td>northern Canning Basin Coast; tropical semi-arid; wave- and tide-dominated, in a macrotidal regime</td>
<td>Type 7 and Type 11; type section</td>
<td>cliff cut into Holocene shoaling tidal sand flat, beach, and dune deposits now lithified to limestone (Willie Creek Calcarenite, Kennedy Cottage Limestone, Horsewater Soak Calcarenite; Semeniuk 2008); type location for the Willie Creek Calcarenite, Kennedy Cottage Limestone, Horsewater Soak Calcarenite; oolitic limestone; earlier Holocene bouldery tempestite deposits in the limestone; earlier Holocene bubble sand and other beach sedimentary structures; sea- history; rocky shore cut into Holocene limestone; beach rock exposures; erosion by tidal creeks; ridge-and-runnel coastal forms (Semeniuk 2008)</td>
</tr>
<tr>
<td>Gantheaume Point, Broome</td>
<td>northern Canning Basin Coast; tropical semi-arid climate; wave- and tide-dominated, in a macrotidal regime</td>
<td>Type 10 and Type 12; type section</td>
<td>Mesozoic sandstone (Broome Sandstone) exposed in high cliffs in a wave dominated and macrotidal oceanographic setting; exposure of platforms, tessellated pavements, ramps, notches, benches, boulder talus, tafoni, etched surfaces; type location for the Broome Sandstone; exposure of details of sedimentary lithology and structures such as cut-and-fill and channel forms, cross-bedding in sandstone, conglomerate, mud layers, mud cracks, burrows, mud-flake breccia, unconformably overlain by Mowanjum Sand (Semeniuk 2008) with fissures filled with red muddy sand; breccia and soil developed between Broome Sandstone and Mowanjum Sand; 30-centimetre-sized polygonal cracking and fissure-fills on the surface of the Mowanjum Sand</td>
</tr>
<tr>
<td>Entrance Point, Broome</td>
<td>northern Canning Basin Coast; tropical semi-arid climate; wave- and tide-dominated, in a macrotidal regime</td>
<td>Type 10 and Type 12</td>
<td>Mesozoic sandstone (Broome Sandstone) exposed in high cliffs and stacks in a wave dominated and macrotidal oceanographic setting; exposure of platforms, tessellated pavements, notches, benches, stacks, tafoni, etched surfaces; exposure of details of sedimentary lithology and structures such as cut-and-fill and channel forms, tidal-channel fills, cross-bedding in sandstone, ripple drift lamination, flazer bedding, wavey lamination, conglomerate, mud layers, mud cracks, burrows, mud-flake breccia</td>
</tr>
<tr>
<td>Finucane Island and Salmon Inlet, Port Hedland</td>
<td>Pilbara Coast: in this area consists of local outcrops of Pleistocene limestone (islands), and coastal fringing Quaternary sedimentary deposits; tropical arid; wave- and tide-dominated, macrotidal regime</td>
<td>Type 5 and Type 10</td>
<td>Pleistocene oolitic limestone forming a shore-parallel barrier (Semeniuk 1996c); limestone exposed in moderately high cliffs in a wave-dominated and macrotidal oceanographic setting; exposure of platforms, benches, tafoni, etched surfaces; exposure of details of sedimentary lithology and structures in the limestone, including a Pleistocene unconformity and Pleistocene shoreline boulder deposit, unconformably overlain by Holocene shell gravel and dune sand with fissures filled with shell and sand (Semeniuk 1996c); sea- history</td>
</tr>
<tr>
<td>Location</td>
<td>Description</td>
<td>Tidal Type</td>
<td>Notable Features</td>
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<tr>
<td>Hearson Cove, and Dampier Archipelago</td>
<td>Pilbara Coast: in this area consists of outcrops of Precambrian rocks (islands) sheltering Quaternary sediment-filled embayments; tropical arid; wave- and tide-dominated, macrotidal regime</td>
<td>Type 5 and Type 12</td>
<td>Precambrian igneous rock contact between intrusive gabbro/dolerite sill and country rock granite; lithological and grain-size layering in the gabbro/dolerite; lithological variation in the gabbro/dolerite; extremely coarse pyroxene crystals in the gabbro towards its base; granophyre textures in the granitoid as a result of the gabbro/dolerite intrusion; inundated (formerly terrestrial, hill-flanking) boulder deposits now forming a bouldery shore; Hearson Cove is the seaward edge of a prograded, sediment-filled former strait; high level mid-Holocene cementation of the boulder deposit (essentially a bouldery “beach-rock”); modern beach rock locally occurring along the Hearson Cove beach; extremes of facies variation within Hearson Cove (gravel grading to fine sand to muddy sand in response to graded wave energy); geomorphic/sedimentologic nature of the shore; reflective beach and dissipative sand flats, and recurring beach cusps formed in shell gravel and in various grades of sand</td>
</tr>
<tr>
<td>Maitland River delta, Dampier Archipelago region</td>
<td>Pilbara Coast: in this area consists of outcrops of Precambrian rocks (islands) sheltering Quaternary sediment-filled embayments; tropical arid; wave- and tide-dominated, macrotidal regime</td>
<td>Type 6 and Type 11</td>
<td>wave-dominated macrotidal delta, comprised of prograded (seaward) sand ridges, mud- and sand-floored inter-ridge lagoons, sandy cheniers, and mud-floored tidal flats, with the mid-to high-tidal mud-and-sand sequence shoaling from sandy and shelly sand low-tidal flat sediments (Semeniuk 1996c); mangrove facies in mid- to high-tidal zone; muddy sediments, mangrove facies; and low tidal sandy sediments are mostly bioturbated; surface structures at fine scale comprised of sand ripples, mud cracks, mud flakes, and burrow punctures</td>
</tr>
<tr>
<td>Goat Point, Shark Bay</td>
<td>Carnarvon Basin coast; in this location within the ridge and gulf complex of Shark Bay; Subtropical arid, wave-dominated, microtidal regime</td>
<td>Type 8 and Type 12</td>
<td>sea cliff cut into an aeolian mound of Pleistocene oolitic limestone (Carbla Oolite); type location for the Carbla Oolite (Logan et al. 1970); cliff shows aeolian cross-layering, and a Pleistocene shoreline breccia; the coast is also biogenic in the tidal zone, and comprised of stromatolitic reefs</td>
</tr>
<tr>
<td>Gascoyne River delta</td>
<td>Carnarvon Basin coast; in this location to the north of the ridge and gulf complex of Shark Bay; Subtropical arid, wave-dominated, microtidal regime</td>
<td>Type 6 and Type 11</td>
<td>wave-dominated microtidal delta, asymmetric because of strong southerly winds, comprised of prograded repetitive sand ridges, mud- and sand-floored inter-ridge lagoons, with mangrove facies in the mud-floored lagoons, shoaling from a sandy mid-to low-tidal flat beach and bar (Johnson 1982); the wave-dominated low-tidal sandy beach and bar sediments are laminated and cross laminated, wind-dominated supratidal dune (sand ridge) sediments are large-scale cross laminated; protected and biogenically altered mid- to high-tidal sediments are mostly bioturbated; surface structures at fine scale comprised of sand megaripples, sand ripples, shell pavements, mud cracks, mud flakes, and burrow punctures</td>
</tr>
<tr>
<td>Location</td>
<td>Description</td>
<td>Type</td>
<td>Notes</td>
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<tr>
<td><strong>Red Bluff, Kalbarri</strong></td>
<td>Carnarvon Basin Coast: this area consists of local outcrops of Silurian sandstone, Pleistocene limestone amid Holocene deposits; Subtropical semiarid climate; wave-dominated, microtidal regime</td>
<td>Type 2 and Type 12</td>
<td>Silurian sandstone exposed in high cliffs in wave dominated and microtidal oceanographic setting; rocky shore of platforms, benches, notches, ramos, boulder talus, tafoni, etched surfaces; cliff exposures sedimentary lithology and structures, such as cut-and-fill and channel forms, cross-bedding, cross-bedding in sandstone, conglomerate, mud layers, mud cracks, vertical burrows, animal tracks, mud flake conglomerate and breccia, slump structures and other deformation structures (convolute bedding); unconformably overlain by Quaternary deposits such as yellow sand and aeolian calcarenite</td>
</tr>
<tr>
<td><strong>Muderup Rocks, Cottesloe</strong></td>
<td>Perth Basin Coast: this area consists of local outcrops of Pleistocene limestone and Holocene deposits; Subtropical semiarid climate; wave-dominated, microtidal regime</td>
<td>Type 3 and Type 12</td>
<td>rocky shore cut into Pleistocene limestone showing former Pleistocene rocky shore unconformably overlain by a Pleistocene beach-to-dune sequence (Semeniuk &amp; Johnson 1985); modern rocky shore showing classic geomorphic sequence of rim, platform, overhangs, cliff and notch, benches, pools, lapiés, talus breccia, and gravelly deposits; earlier Pleistocene rocky shore features of potholes, overhangs, shell gravel, lithophagic borings, echinoid excavations, bouldery deposits; one bench is an exhumed Pleistocene rocky platform; Pleistocene beach/dune stratigraphy shows shoaling-upward sedimentary sequence, with beach to dune sedimentary structures, bubble sand, and Sepia and Spirula fossils; sequence is punctured by vertical pipes filled with yellow sand and riddled with rhizocretions; unconformably overlain by yellow sand</td>
</tr>
<tr>
<td><strong>Point Becher, cuspat foreland, Rockingham</strong></td>
<td>Perth Basin Coast: this area consists of local outcrops of Pleistocene limestone and Holocene deposits; Subtropical subhumid climate; wave-dominated, microtidal regime</td>
<td>Type 7 and Type 11</td>
<td>Holocene prograded coastal plain comprised of low beach ridges (Searle et al 1988; C A Semeniuk 2007), and a variety of coastal dune forms (Semeniuk et al. 1989); underlain by a shoaling sequence of seagrass facies sediments, beach and dune sediments; two orders of beach ridges reflecting Double Hale Cycle influence on Indian Ocean climate, and the 250-year climatic cycle (Semeniuk 1995a): Point Becher preserves a history of beach ridge accretion and erosion reflecting the 250-year climatic cycle (Semeniuk 1995a; C A Semeniuk &amp; Semeniuk 2013); Holocene sea- history preserved in the stratigraphic sequence (Searle et al. 1988)</td>
</tr>
<tr>
<td><strong>Leschenault Peninsula barrier dune</strong></td>
<td>Perth Basin Coast: this area consists of shore-extensive Holocene deposits; Subtropical subhumid climate; wave-dominated, microtidal regime</td>
<td>Type 7 and Type 11</td>
<td>Holocene retrograding barrier dune system (Semeniuk &amp; Meagher 1981a; Semeniuk 1985a) underlain by dune sand (Safety Bay Sand) and estuarine sediments (Leschenault Formation); modern barrier illustrating staggered parabolic dune development, and its geomorphic evolution to soil-covered plain; complex Holocene sea-level history and climate history preserved in the stratigraphic sequence (Semeniuk 1985a, 1986c)</td>
</tr>
</tbody>
</table>
Application of coastal types in the proposed coastal classification

A summary of the hierarchical structure and what is treated within each scalar level is shown in Figure 6.12. The categorisation of coastal types at the three levels presented in this Thesis can be applied to develop an inventory of coastal features, and leads to comparison and assessment of geological and (hence) geoheritage values. Level 1 provides a context and framework for subdivision and interpretation of the significance of coasts of different geological, climate and oceanographic regions. In Western Australia, using Precambrian rock coasts as an example, as noted earlier (Figure 6.11), the range of geological features in the folded Precambrian system of the King Leopold Mobile Zone of the south-western Kimberley region will be different to those of the Precambrian igneous complexes of the Pilbara region and to those of the Precambrian Albany-Fraser Orogen along southern Western Australia.

Similarly, Quaternary limestone-dominated rocky shores cut into Quaternary limestones of the central Perth Basin occurring in a subtropical/temperate subhumid microtidal and wave-dominated settings will exhibit different geologic and geomorphic features to rocky shores cut into those of the northern Pilbara Region and the Canning Coast Region occurring in tropical arid, macrotidal and wave-dominated environments (Figure 6.13). The former are composed of biogenic calcarenite with stratigraphy of Pleistocene beaches and dunes (Semeniuk & Johnson 1982) and have developed a simple coastal morphology of platform, notch, cliff and bench (Semeniuk & Johnson 1985). The latter are composed of oolitic calcarenite with stratigraphy of Pleistocene dunes and have developed a more complex coastal morphology of platform, notches, cliffs and benches (Semeniuk 1996c).

The classification at Level 2 is based on identifying coasts developed by processes of marine inundation, erosion, sedimentation, biological activity, and diagenesis (Chapter 4). It identifies the different coast types that can be comparatively assessed for their general to specific geoheritage value, and can be applied at the largest scale and the finer scales of coastal expression. The classification at Level 2 is designed for use in assessing geoheritage significance and geoconservation. Firstly, it identifies the fundamentally different types of coasts that form a framework for more detailed studies. Secondly, it identifies those that have specific geoheritage significance or value. Thirdly, it can be used for comparative assessment, e.g., coasts of inundation forms can be compared to other inundation forms, and erosional coasts can be compared to other erosional forms, and those that illustrate Holocene history or earlier geological history can be compared to a similar category of coast elsewhere. In this context, use of the coastal categories provides a consistent approach for comparative assessments in geoconservation and geoheritage, and a systematic approach for classifying, cataloguing, and assessing sites for geoheritage purposes.

Classification at Level 2 also deals with the intergradation between coasts by recognising the intermediate forms (e.g., eroded coasts with sediment accumulations) as separate coast types. The classification at Level 2 also addresses the fact that different categories of coastal features (and therefore different categories of coastal features of geoheritage significance) can occur at different scales. In application, the classification is non-scalar (i.e., the coastal types transcend scale), hence there is a focus on form and type, regardless of scale and, once identified and classified, coastal features can be related to a scale by descriptors. This is not to say that some coastal features are not specifically related to a given scale, or do not have a tendency to occur within a specified scale range. Some coastal types, such as rias of the Kimberley region, and the limestone barriers of the Pilbara region, are expressed more consistently at a regional scale, while others, such as beach rock ramps along tropical Western Australia, are expressed more consistently at local scales, but many other coastal types can be recognised within varying frames of reference. Classification at Level 2 also provides a context for describing, comparing and assessing sites of geoheritage significance at the finer scale within a consistent framework – thus, fine-scale coastal features are compared only within similar coastal types.

Because the classification at Level 2 is designed for geoheritage purposes, some of the categories do not correlate with existing classifications (though this is not strictly necessarily the case). Coastal Types 1-7 form a natural gradational series (starting with a Holocene marine inundated landscape), with a trend resulting from increasing erosion on one hand versus a trend resulting from increasing
sedimentation on the other, and are conceptually parallel, in part, to some existing classifications (e.g., Valentin 1952 and Bloom 1965). However, Coastal Types 10, 11 and 12, identified as types because they record Holocene history of sea-level changes, tectonism, oceanography, or climate, or record pre-Holocene geology, are not addressed in existing coastal classifications even though such coasts can be of geoheritage significance and need to be addressed in a classification of coasts. In summary, Coastal Types 1, 2, 3, 5, 6 and 8 are, in part, covered by some existing coastal classifications, or conceptual classification schema, but Coastal Types 4, 9, 10, 11, and 12 are not recognised in existing classifications. The reason for this, as noted earlier, is that geoheritage and geoconservation have not been the basis for developing previous coastal classifications.

Using the proposed classification, a given coastal type can be classified from a number of different perspectives, and therefore can be classified as having different geoheritage values. Eroding rocky shores exemplify this. An eroding coast can be classified as Coastal Type 3, illustrating modern coastal forms developed in response to marine erosion (i.e., products formed in response to modern processes), with formation of vertical cliffs, wave-cut benches, lithologically-determined benches, cementation-determined benches, talus, and various microtopography. The same sea cliff, if exhibiting geomorphic features and cementation features developed during a former higher sea level, can also be categorised as Coastal Type 10. If there is significant stratigraphy, or other geological content, exposed in the wave-washed cliff, the coast may also be categorised as Coastal Type 12.

The different geomorphic aspects of the coast, and different geologic components of the coast, as well as features at different scales along a given tract of coast, may have different geoheritage significance. These matters have to be addressed in identifying sites of geoheritage significance. In Shark Bay, for example, there are numerous small-scale coastal features of geoheritage significance that are embedded in larger-scale coastal systems that in their own right are of geoheritage significance. Small-scale features of geoheritage significance in Shark Bay include breccia pavements, or gypsum rosettes. Large-scale features of geoheritage significance include the marine-inundated ancestral topography of ridges-and-gulfs that is a feature reflecting the tectonically-active western margin of the Carnarvon Basin. Siccar Point in Scotland provides another example: the unconformity at Siccar Point has global (historical cultural) geoheritage significance and, in the context of the unconformity and the Devonian rock succession, it is undoubtedly of national significance (Barclay et al. 2005), but at the geological and geomorphological small scale, as a rugged coast of rocky shores cut into Silurian and Devonian rocks, with cliffs and platforms, which are well developed in the United Kingdom, it is a site of geoheritage regional significance occurring at the geomorphic medium scale (Brocx & Semeniuk 2007). To be useful for studies in geoheritage, and for geoconservation, the various scales at which natural features express themselves need to be considered and noted by using a scale descriptor and assessed independently.

As noted in the review, classification of the coastal zone and its smaller-scale products have been reported from a number of disciplines and number of perspectives with the result that there are a variety of systems, and a wide range of detailed studies that categorise the large scale and finer scale products along the coast. Coastal geomorphologists and sedimentologists have classified/categorised the coast globally, regionally, and locally, providing over-arching and/or theoretical schemes at one extreme, and identifying smaller-scale features of the coastal zone at the other. The over-arching classification systems and other existing coastal classifications have not been used in this Thesis for a number of reasons. Firstly, in a context of geoheritage and geoconservation, the conceptual models, while useful for understanding the development of coastal forms, do not provide categories of coast for empirical and comparative purposes. Secondly, coastal scientists have had different objectives, and their classifications and categories have not always been applicable across disciplines, and specifically have not been directly applicable to geoheritage and geoconservation. The approaches adopted by geomorphologists, for instance, have not always been applicable to sedimentology, and vice versa, and that of identifying diagenetic products has not been applicable to geomorphology, sedimentation, or to erosional coasts. From the variety of studies cited above, information useful to geoheritage and geoconservation are the categories of coastal types that have been identified to date (e.g., rocky shores, delta types, barriers dunes, cuspate forelands, beach cusps), and smaller-scale products such as bedforms, sedimentary structures, and fine-scale rocky shore features, amongst others (and these are mainly applicable at Level 3). Thus, the approaches in coastal geomorphology,
sedimentology, and diagenesis have not been directly applicable to the issues of geoheritage except at the lowest level of classification of categories that may be used in comparative inventories, or in compiling assemblages of smaller-scale features at a given site.

Diagenesis provides a good example, which will be outlined in four detailed paragraphs below to illustrate the lack of communication between the various disciplines in coastal science, and how this has led to a lack of classification of coastal forms based on this important coastal attribute. Categorisation of diagenetic products to date has not been directly useful to the issues of geoheritage and geoconservation.

Researchers of modern diagenesis have categorised coastal diagenetic features, but have tended to concentrate on its specific interesting effects (Ginsburg 1953; Bricker 1971; Logan 1974; Bathurst 1975; Parker & Sellwood 1983; Schroeder & Purser 1986; McIlreath & Morrow 1990; Tucker & Bathurst 1990). They have therefore focused on smaller-scale products, documenting site-specific products, and providing information useful for interpreting ancient sequences, with an emphasis on diagenetically susceptible materials such as carbonate sediments in arid and hypersaline environments. Generally, the approaches have not presented diagenesis as a unified discipline for coastal science, and the results have not always been transferable to the other areas of coastal science. As such, information on diagenesis, scattered in the literature, does not provide a framework for coastal classifications based on diagenetic products. Coasts, in fact, generally are not classified on their diagenetic products, and those formed by diagenesis are not generally recognised as a coastal type. Rocky shores well illustrate this: diagenesis is an important process and product component along rocky shores, especially those cut into porous Quaternary limestone, but its role in shore development and control of microscale and leptoscale features has not been fully explored. So while there is mention of the diagenetic products, the role of diagenesis in coastal development generally has seldom been considered. A perusal of a range of texts dealing with coastal science sometimes will find beach rock (a product of diagenesis) in the index, but not diagenesis itself. The corollary is that the results of most studies on diagenesis (as processes, or products), cannot be imported into geoheritage and geoconservation. Diagenesis in Shark Bay is used to further illustrate this principle.

Shark Bay has been designated a World Heritage area (inscribed in 1991; UNESCO 1991) and, as such, it has global, national and state-wide importance. Amongst other aspects of its natural history, it is comparatively well researched in terms of Holocene diagenesis (Logan 1974). Shark Bay is one of the few World Heritage properties listed for all four outstanding natural universal values: (1) an outstanding example representing the major stages in the earth's evolutionary history, (2) an outstanding example representing significant ongoing ecological and biological processes, (3) an example of superlative natural phenomena, and (4) containing important and significant habitats for in situ conservation of biological diversity. While the geological significance of stromatolites and seagrass banks, and its salinity structure are mentioned in the criteria for selection (UNESCO 1991), paradoxically however, diagenesis is not emphasised as a natural process that has any international or national significance, and there is a general lack of appreciation of the relevance and applicability of diagenesis, to date, to coastal geomorphology and to geoheritage and geoconservation in Shark Bay.

While diagenetic processes and products at Shark Bay were systematically described by Logan (1974) in a stratigraphic/hydrochemical framework, and the study was relatively exhaustive, some of the globally significant and unique diagenetic processes and products in the Shark Bay area were not highlighted. The study by Logan (1974) neither provided a framework, nor results, nor global comparison which could be used for geoheritage and geoconservation, even though many of the diagenetic processes and products are globally significant. Even comparing the results from Shark Bay to other areas globally could have formed the basis of geoheritage comparisons or assessment. Moreover, the results of the study of diagenesis in Shark Bay were not applied to matters of coastal geomorphology, coastal erosion, or many other of the aspects of coastal sedimentation. These outcomes are not surprising, as the objective of the study by Logan (1974) was an inventory of Holocene diagenesis, not a catalogue of diagenetic products for purposes of comparative geoheritage and geoconservation. However, the matter of diagenesis in Shark Bay does illustrate the point that one of the most comprehensive studies undertaken of diagenesis globally cannot be readily compared with other sites elsewhere, nor can it be easily transferred to matters of geoheritage and geoconservation,
except on an inventory basis, to catalogue diagenetic features that may be of geoheritage significance. This example from Shark Bay underscores that diagenesis as a process resulting in diagnostic coastal types. Its effect in controlling and modifying coastal form has been largely overlooked by coastal scientists.

Coasts present many products of geoheritage significance, from varying expression of landforms, to products uniquely developed in the coastal zone from the interaction of coastal processes, to sea cliffs that reveal Earth history, but coastal deposits and coasts also can uniquely record a Quaternary history of sea level, climate, and oceanic processes because they interface with oceans. Such stratigraphic and biostratigraphic sequences in Western Australia have been used to document relative sea-level changes (Semeniuk 1985a, 1996b, Semeniuk & Searle 1986, Playford 1988, Searle et al 1988, Semeniuk 2008), as represented by Coastal Types 10 & 11. Encoding of climate patterns is discussed further below.

The oceans dominate the Earth’s surface, and act as large receptors for solar radiation, encoding climate changes in a number of ways. Though not strictly globally homogeneous (in terms of salinity, temperatures, and circulation), oceans are much less heterogeneous than landmasses that can express variable geology, landscape, soils, and vegetation at regional to small scales (Hill 1962, 1963; Gross 1972; Long 1974; Press & Siever 1974; Brocx & Semeniuk 2009a). Consequently, terrestrial environments respond to climate changes in more complex ways than oceans. It was partly for this reason, to study Quaternary climate changes, that stratigraphers and palaeoclimatologists concentrated on cores and biostratigraphy of deep ocean basins where there was/is a degree of environmental spatial consistency. In essence, therefore, the oceans can more consistently register the effects of short-term to long-term climate changes but, with oceans being fluid and circulating, the effects of climate can be relatively rapidly dispersed and not necessarily preserved. However, the coast, being the edge of an ocean, regardless of whether it is erosional or depositional, is an important zone where oceanic patterns reflecting climate and sea-level history can be recorded in landforms, sediments, biota, and isotopes, and can be read, if the alphabet of the encoding is manifest as landform, stratigraphic, biostratigraphic, and isotopic signatures. In Western Australia, the Holocene sequence of the Rockingham-Becher Plain in its regularly-spaced low-relief beach ridges (Searle et al. 1988) records cyclic climate changes responding to the solar Double-Hale Cycle (Semeniuk 1995a; C A Semeniuk & Semeniuk 2013). Regular beach-ridge patterns recording the solar Double-Hale Cycle also have been documented in Hudson Bay, Canada, by Fairbridge & Hillaire-Marcel (1977). In effect, the coast can be the permanent receiving interface (or the register) of oceanic patterns which are driven by climate changes and sea-level changes (Semeniuk 1995a). In this context, the modern coastal zone can be an important site of geoheritage significance recording the history of the Earth in the Holocene. Stratigraphic sequences and landforms that record this ocean history are represented by Coastal types 10 & 11.

While most of the coastal types identified in this Thesis form part of a natural inter-gradational group or continuum, or are products of interacting processes (i.e., Coastal Types 1-9) reflecting the balance of the five marine and coastal processes, or forming another natural group recording Holocene history (i.e., Coastal Types 10 and 11), sea cliffs are an adjunct category. Sea cliffs emphasise geological content, not coastal geomorphology, nor Holocene history, and are not part of a natural continuum in coastal types shown in Figures 6.2, 6.3 & 6.7.

Sea cliffs provide an interesting example of how a coastal feature can be viewed from different geoheritage perspectives. Viewed strictly as sea cliffs, i.e., geomorphologically, such coastal features would be captured as various categories in the classification presented in this Thesis, viz., where erosion has partly modified the coast (Coast Type 2), or has fully modified the coast (Coast Types 3 & 4), and in this context, the emphasis on these types of coasts is geomorphological. Different sea cliffs composed of diverse materials would respond variably to coastal processes, and would provide geomorphologically, geologically, and processes-oriented information useful to science and to coastal managers. Sea cliffs can also preserve ocean history and sea-level history in benches and platforms (Coast Type 10). As mentioned earlier, Coast Type 12, sea cliffs, emphasise geological content, not geomorphic features.
Brocx & Semeniuk (2009a) pointed out that sea cliffs generally provide excellent locations for studying rock sequences (sedimentary, igneous, or metamorphic), and provide some of the best exposures of geological features of geoheritage significance. Indeed, there are numerous such examples that already have been afforded global and national recognition because of their geological or cultural importance - these include the chalk cliffs along the Sussex coast in southern England (with their sedimentary structures, chert nodules, fossil assemblages, and Holocene chert-pebble conglomerate and relict landforms; Gallois 1965; Melville & Freshney 1982; Mortimore et al. 2001), the unconformity exposed at Siccar Point in Scotland first described by Hutton, cliffs along the coast of Victoria (White et al. 2003), and at Hallett Cove in South Australia (with its Precambrian to Permian unconformity, buried Permian glacial landscape features, Permian glacial imprints, and Tertiary stratigraphy; Parkin 1969; Drexel & Preiss 1995). Fine- to small-scale rock structural features, intra-lithologic features, and various lithologic types are brought out best by coastal erosion effected by wave washing, (sand-charged) wave erosion, wind erosion, and salt weathering. A range of textbooks on sedimentary structures and other geological features from the realm of sedimentary, igneous, metamorphic rocks, and structural geology reveal that a large number of well-exposed outcrops occur in the coastal zone (e.g., Pettijohn & Potter 1964). In contrast to outcrops inland or along river courses (apart from regularly river-washed steep gorges), coastal outcrops not only present wave-washed and salt-weathered exposures, but also generally a better continuity of outcrop (Brocx & Semeniuk 2009a). A corollary is that coastal rock exposures are often also the best outcrops for type sections and reference locations. In Western Australia, the Broome Sandstone at Gantheaume Point (Brunnschweiller 1954), the Toolinna Limestone along the edge of the Nullarbor Plains (Lowry 1970; Geological Survey of Western Australia 1990), and the Carbla Oolite at Goat Point, Shark Bay (Logan et al. 1970) exemplify this.

While type sections, reference sections, teaching sections, culturally-important geological sites, and sites that exhibit geohistorical information are variably captured in the twelve coastal types, it needs to be stressed that if they are to function as important geological sites, generally they should be relatively fixed (e.g., cliffs) and able to be examined and revisited as knowledge expands and new research directions are developed. Along the same lines, some of the active, dynamic coastal terrains where they are relatively long-term features can function as standards and reference locations that can be examined and revisited - for example, the mobile parabolic dunes of the Leschenault Peninsula (Semeniuk & Meagher 1981a), or that of the Yeagarup Dunes along the southern coast of Western Australia (C A Semeniuk & Semeniuk 2011a). Other active coastal forms appear to be relatively temporary or ephemeral, e.g., near-shore subtidal ridge-and-runnels, and beach cusps, and might not be viewed as qualifying to be assigned geoheritage significance. However, the argument is presented that where rips, ridge-and-runnels, and beach cusps are regularly developed at some locations (because of the configuration and orientation of the shore, the occurrence of headlands framing a curved beach or cove, combined with the prevailing wave climate), they stand as important teaching and research laboratories. Rips, ridge-and-runnels, and beach cusps, while they may not strictly be permanent systems on a day-to-day basis, may be quasi-prevailing or regularly occurring for reasons outlined above. Hence, there are locations where they can be predicted to more regularly occur. Also, as particular types of rhythmic coastal features, they can develop coastal formations and stratigraphic sequences indicative of specific coastal conditions (e.g., large-scale cut-and-fill structures, lenses of trough-beded sand, lenses of upward-shoaling sedimentary packages, shell and coarse sand lenses, and shell-lag deposits, amongst others; Brocx & Semeniuk 2009a, 2010a). As natural reference sites, classrooms, and research sites, sites with quasi-prevailing or regularly occurring rips, ridge-and-runnels and beach cusps should be considered as of geoheritage significance in the category of sites of active coastal geological processes.

The recognition of the twelve types of coast with different geomorphology and geological features, and the reasons for their differentiation, provide the template for identifying geodiversity and the importance of the geology in developing the coast. Recognition of the twelve types of coast forms the first step to identifying sites of coastal geoheritage significance. Thereafter the various coastal forms and coastal features can be readily assigned to the four categories of geoheritage sites as described by Brocx & Semeniuk (2007).
The coastal types described in this Thesis can be placed into a larger context, within a national or international framework, using information on geological setting (including tectonic setting) and hinterland geomorphology, as well as climate setting and oceanographic setting. The context of the coast would influence its detailed geomorphic, sedimentological, erosional and diagenetic responses. Tectonic setting, for instance, would control the developing shore morphology, the types of hinterland geomorphology that are presented at the shore, the erosion and sedimentation rates, and the types of sediment delivered to the shore. Geological setting would determine the coastal bedrock geology, which would control the “grain of the coast”, the configuration of the coast, the structural and lithological controls on coastal form, the erodability of the shore, and the types of rock sequence that might be exposed. Hinterland geomorphology, once inundated by the Holocene transgression, would determine coastal forms in terms of shapes, steepness of shore, and riverine and marine interactions. Climate setting would determine water temperatures, and coastal processes in terms of tropical humid or tropical arid conditions at one extreme, to boreal and arctic conditions at the other (with ice interacting with coastal deposits, or annual freezing of coastal deposits), or would influence wind direction and intensities, rainfall, run-off volumes, evaporation, style of diagenesis, and effect of biodiversity, amongst others. Oceanographic setting would determine whether the coast is swell-, wind-wave, tide-dominated, or cyclone-affected, and the prevailing direction of wave impingement.

These higher order settings provide a context for national and international comparisons of the twelve coastal types so that features of geoheritage significance can be systematically compared and ranked. However, the underlying continental-scale reason for the development of a coastal type (e.g., tectonic collision coast along a plate edge, or an arid coast) is outside the scope of this Thesis. They have been briefly described because these higher order classification levels are useful in global comparisons of coasts for geological/tectonic purposes, but not for comparing coasts at the level at which smaller-scale geoheritage values are being assessed.

The hierarchical approach to classifying coast proposed in this Thesis requires all three levels to be applied to be able to fully categorise a coast for assessing geoheritage values and for geoconservation (Figure 6.12). Applying only Level 1, i.e., placing the coast in a geological, oceanographic and climatic context, clearly does not provide enough detail for delineating coastal forms for geoheritage purposes – it would just locate the coast geologically, climatically, and oceanographically without providing critical coastal product(s) information. However, the context provided by Level 1 classification is critical to application of Level 3.

While the benefits of Level 2 classification include categorisation of coastal types and, in the context of Coastal Types 10, 11 and 12, identification of different coastal forms with geoheritage significance, on its own, does not allow for detailed comparison of coastal types. For instance, for Coastal Type 3, the different types of eroded coasts occurring along the Baxter Cliffs, or along limestone rocky shores in the Carnarvon Basin, or cliffed igneous rocky shores in the Pilbara would not be able to be separated. For Coastal Type 6, the different types of accretionary coasts, such as cuspate forelands, beach ridge plains, barrier dunes and deltas, similarly, would not be able to be separated. However, Level 2 classification does provide a context for the subdivision that would follow, with application of Level 3 classification and, used in conjunction with regional setting at Level 1, provides a solid foundation to separating coastal types and provides a basis for comparing and assessing geoheritage values.

Applying Level 3 classification in isolation, i.e., documenting a given coastal site in detail will result merely in an inventory of geomorphic and geological features. However, the importance of information at Level 3 is that it separates the various coastal types on their finer structure, characteristics, and components, and can be used comparatively in an assessment capacity for determining geoheritage values. While Level 3 involves the smallest scale of information applied, its content will depend on the larger scale geological, oceanographic, climate setting, and the finer scale information will have geoheritage relevance when used in conjunction with both the regional setting context and with Level 2 classification of the coasts.
In essence, for geoconservation and assessment of geoheritage significance, all three levels of coastal classification have to be applied.

As noted earlier, classifying coastal sites for purposes of geoheritage and geoconservation is not an easy task. In recognition of the complexity, intergradation, and variety of scales of coastal features, a design of a category-oriented (or product-oriented) classification has been attempted to deal with types of coasts that can be applied to a wide variety of settings. By addressing the products developed by the five fundamental processes (of marine inundation, erosion, sedimentation, biogenic processes, and diagenesis), the proposed classification at Level 2 captures the main coastal categories for purposes of assessing geoheritage significance and forms a basis for comparative assessment of sites, and a framework for a more detailed inventory as a basis for selection of sites for geoconservation. The rationale is that if the main coastal settings and main processes, and their combinations, that develop coast types and coastal products, have been identified then this classification has captured the higher order levels of coastal categories. The classification approach presented herein addresses the types of coasts that are developed geomorphologically, the stratigraphic sequences that may be developed, the geohistorical record within coasts and coastal sequences, and the products of hydrochemical interactions – all aspects of the coast that can have geoheritage significance. In this context, smaller-scale geological and geomorphic features can be identified for comparative purposes. But, conversely, any fine scale feature along the coast can be placed into the framework of category-oriented coastal types for inventory-based assessment to determine geoheritage significance.

While the approach presented in this Thesis is largely based on Western Australian examples, a review of the literature and site visits to locations elsewhere in Australia and overseas, show that it has potential for global applicability. Identifying geological region and climate and oceanographic setting clearly provides important information for understanding coasts, and is applicable globally. The literature already shows these underlying factors to have major influence on geological content for geoheritage purposes, as well as on coastal processes, and coastal form (Davies 1980; Woodroffe 2002). At the next level, by addressing the products developed by the five fundamental processes the proposed classification of twelve coastal types captures the main coastal categories and, as such, forms a basis for comparative assessment of sites of geoheritage significance and the selection of sites for geoconservation.

Many studies in coastal geomorphology, erosion, sedimentation and diagenesis have only been applicable to the issues of geoheritage and geoconservation at the specific product level (such as delta types, barrier islands, coastal dunes, as large scale features, or ripple forms, beach cusps, flaxter bedding, as small/fine scale features). Such coastal categories are only useful as comparative inventories. In contrast to other coastal studies which describe, categorise, and classify coasts and their products, the classification presented here provides the basis for a systematic inventory-based assessment of coastal types and products for geoheritage and geoconservation.
Chapter 7: The Geoheritage Tool-kit as a method for selecting sites of geoheritage significance

Conventionally, there are a number of stages in geoconservation, beginning firstly with the recognition that there are sites of geoheritage significance that need to be conserved (Brocx & Semeniuk 2007, 2009b, 2015a) and how this can be achieved, leading to the final outcome either of a register deriving from *ad hoc* geoconservation, or a register of geological features deriving from an inventory-based (category-based) and theme-based approach (Doyle *et al*., 1994; Wimbledon *et al*., 1995, 1996; Brocx 2008). For instance, since 1949, the assessment and subsequent selection of sites in the United Kingdom has been undertaken on the basis of a series of blocks which may be based on geological time, subject, or regional divisions, or combinations thereof (Ellis 2011), and in 2001-2002 ProGEO contributed to a number of important geoconservation initiatives that included the incorporation of a policy statement relating to the importance of geology and physical landscapes in the Pan-European Biological and Landscape Diversity Strategy (ProGEO 2002; Wimbledon & Smith-Meyer 2012).

While British and European approaches to develop an inventory of geological features of significance have been successful towards the goal of geoconservation in that numerous and varied aspects of geology have been identified and secured in conservation reserves, the approach has been thematic. This is because the geology of British and European terrains is reasonably well known and the countries are relatively small. In contrast, Western Australia presents a vast array of quite varied geological features from Archaean metamorphic and igneous terranes and geological systems to Proterozoic rock systems to Phanerozoic stratigraphy, lithology, palaeontology, mineralisation, etc., representing a wide diversity of ancient and modern geological processes and products. Further, with their region-specific geology, stratigraphy, and geological history, the themes of British and European geoheritage are not suited to the geological setting of Australia and, more specifically, Western Australia. Therefore, an alternative hierarchical-based system has been designed for use in Australia (which can also be applied elsewhere) to systematically identify and assess sites of geoheritage significance. It is termed the "Geoheritage Tool-kit" (Brocx and Semeniuk, 2009, 2011a) and can be used to systematically compile an inventory of the full range of geological and geomorphological features (geodiversity) of an area at various scales, assign geological sites to various conceptual categories of geoheritage, assess their levels of significance, and address whether geoheritage features are treated in isolation or as inter-related suites that should be conserved as an ensemble.

The “Geoheritage Tool-kit” is defined as follows: *a procedure, or series of steps (or conceptual tools) that enable a geoheritage practitioner to systematically identify and categorise areas, geosites and/or features of igneous, metamorphic, sedimentary, stratigraphic, structural, geochemical, mineralogic, palaeontologic, geomorphic, pedologic, hydrologic, and other aspects of geoheritage significance within a given natural region or terrane, allocate them to a conceptual category of geoheritage and to a scale of reference, and assess their level of significance* (Figure 7.1). In terms of information and data collected, some parts of the “tool-kit” identify categories (nominal data and categorical data, *e.g.*, identification of regions, or the allocation of sites to category of geoheritage, respectively) while some are ranked semi-quantitatively (*e.g.*, assessment of significance, and allocation to scale of reference).

Bearing in mind that not all aspects of the geology of the Earth would be present in one region, and not all aspects of the geology of a region may be of geoheritage significance, the steps in the “Geoheritage Tool-kit”, after identifying geological regions, seek to compile an inventory of the geological essentials comprising that region, and assess their significance. The application of the Geoheritage Tool-kit assumes that the wider definition of what constitutes geoheritage, as discussed in Brocx and Semeniuk (2007) is being applied. There are three scales at which the Geoheritage Tool-kit can be employed, as outlined below:
1. **geological region scale application**: to comprehensively, exhaustively investigate and assess largely unknown areas at the scale of geological regions for their potential to contain features of geoheritage significance; the approach is to systematically compile and assess the geological essentials of areas/regions from first principles to develop a comprehensive inventory of their geological/geoheritage features; this is usually undertaken within the confines/boundary of a single and defined geological region, or can be undertaken in areas that have a number of geological regions as long as the inventory of geological/geoheritage features are compartmentalised for each geological region; the investigation and assessment of an area in *Morocco de novo* by Errami *et al.* (2014) is an example of this approach;

2. **site-specific or area-specific application**: to investigate and assess the features of selected, specific sites or small areas; the approach here is to systematically compile and assess the geological essentials of those smaller sites or areas in terms of the features of geoheritage significance but within an already known framework of the geological region (as determined from the literature); the area-specific or site-specific investigation will be wholly within a geological region; the description and assessment of Muderup Rocks stratigraphically and geomorphologically described previously by Semeniuk & Johnson (1982, 1985) and the Willie Creek cliffs stratigraphically described previously by Semeniuk (2008) 1982, 1985), to be presented later in this Thesis in Chapter 8, are examples of this approach;

3. **application to a pre-existing ad hoc inventory**: the approach is to sort pre-existing information on geological/geoheritage features into the confines/boundary of a single and defined geological region as a starting place for further comparison and assessment of geoheritage values, and then sequentially apply the later steps of the Tool-kit; this approach utilises sites and areas already assessed as being of geoheritage significance but refines that assessment by placing them into a context of regions, classifying them as to geoheritage site category, determining the scale of the various geological features, and evaluating their significance for more rigorous comparisons with other perhaps similar or superficially similar sites; comparison between the Osmington concretions, the Bowling Balls Beach concretions, and the Moeraki Beach concretions, and comparisons of Precambrian isoclinal folds in the King Leopold Orogen, in the Pilbara Region, in the Leeuwin Complex, and in the Albany-Fraser Orogen (as described in Table 6.1), are examples of this approach, where detailed use of the Tool-kit would separate the various concretions and various isoclinal folds as being sufficiently different and significant to warrant their separate allocations as sites of geoheritage significance (Figures 6.10 & 6.11).

The use of the Geoheritage Tool-kit, in terms of identifying scale of the geological feature(s), its/their assignment to geoheritage category, and its/their assessment of significance, is essentially the same for the first two levels of application but only differs at what scale is the area of investigation. The steps involved, the practicalities, the principles, and the outcomes resulting from applying the Geoheritage Tool-kit in a site-specific or area-specific manner are the same as those for region-wide application. Only the geological region scale and the site-specific application of the geoheritage Tool-kit will be dealt with in this Thesis because there have been no sites of coastal geoheritage significance (with inventory of geological features) identified to date along the Western Australian coast.

In the cases of geological region scale application, the Geoheritage Tool-kit can be used in regions and large areas that are relatively unknown for their geoheritage values. For instance, it has been applied to the Precambrian region of the Anti-Atlas of Morocco, a geologically distinct region of gently folded Proterozoic to Palaeozoic rocks with embedded large Archaean inliers (Errami *et al.* 2014) to identify and assess various geological features of potential geoheritage significance. It can be applied in a similar manner to many other geological regions in Australia (such as the Pilbara Region comprised of Precambrian rocks in Western Australia, the inland Kimberley Region comprised of Precambrian rocks in Western Australia, and the inland and the coastal Sydney Basin Region of upper Palaeozoic to Mesozoic of eastern Australia), or in other parts of the World that have distinct and large geological regions, such as northern Africa, south Africa, the orogenic parts of China, the Canadian Shield, the Rocky Mountain region of North America, the Appalachian region of North America, and the Andes Mountain region of South America, amongst many others. The results would be comprehensive and exhaustive and would be manpower-intensive to create a database of sites of geoheritage significance.
Given the heterogeneity and complexity of the Western Australian coast, the region-wide application of the Geoheritage Tool-kit across the full length of the coast is beyond the scope of this Thesis. It would involve identifying and assessing hundreds of sites over some 6000 km of overall (overarching) coastline length. Rather, in this Thesis, for coastal Western Australia, the Geoheritage Tool-kit is applied in area-specific or site-specific manner to illustrate its practical use and powers of comparison and assessment of significance.

The method or steps for identifying sites of geoheritage significance using the Geoheritage tool-kit, whether applied area-specifically or site-specifically or region-wide, are described below.

**Step 1 - identify the geological region and environmental setting in which an area, a site, or a feature occurs:** The identification of geological regions and environmental setting provides a natural boundary and the geoscientific context for the area or site being investigated in terms of geological and geoheritage features, and provides an indication of the types of materials and styles of geological features and coastal features that may be expected. It also ensures that comparisons in assessing levels of significance are undertaken wholly within similar geological regions with similar history. Identifying the various geological regions, and then identifying features therein, therefore, is the first stage of a systematic inventory-based approach to developing a database for sites of geoheritage significance according to the scope placed onto geoheritage (i.e., all matters geological). This does not necessarily translate to just listing isolated sites of geoheritage significance but can also lead to or should lead to the identification and linkages to interrelated ensembles of features. In Western Australia, Step 1 also results in recognising major cratons and basins cropping out at, or forming the coast, and the climatic/oceanographic setting of a coastal tract.

The boundary of a region may be defined by the margin of a basin, a terrane, or system of terranes, a geological province, or some generally unifying feature of the geology such as a metamorphic belt, a fold belt, or a suite of igneous rocks. The Chalk of southern England and the Shark Bay area of Western Australia illustrate the concept of a region and that of geological essentials within a region. The Chalk, well exposed along the southern coast of England, is an essential feature of the geology of the region of the southern coast of England, and has geological characteristics of chalk cliffs, chert nodules, various chalk lithotypes, chalk diagenesis, Cretaceous shelly fossils, fossil taphonomy, Cretaceous ichnofauna, Quaternary landforms, hanging valleys, and shoreline ribbons of flint-pebble conglomerate (Gallois, 1965; Melville and Freshney, 1982; Brocx and Semeniuk, 2010). In Australia, Shark Bay, a World Heritage site not replicated elsewhere globally, is a distinct geological region. Some of its essential features include its large scale stratigraphy, the deep-embayed limestone coastal morphology, seagrass banks, the coquina deposits, stromatolites, high-tidal crusts, high-tidal gypsum crystals, gypsum-filled bivalves (a type of hypersaline basin wetland), modern ooid sand banks, Pleistocene oolite, and high cliffs cut into Pleistocene limestone (Logan, 1970, 1974; Brocx and Semeniuk, 2010). For the two examples cited above, the geological essentials tend to be unique and internationally significant and of geoheritage significance.

**Step 2 - compile a list (or inventory) of features that characterise, or are peculiar to, or that are the essence of the area:** Undertake literature reviews, interviews, and/or fieldwork to compile an inventory of the geomorphic, stratigraphic, structural, petrologic, hydrologic, mineralogic, palaeontologic, diagenetic, pedogenic, and other geologic features that characterise, or are peculiar to, that are the essence of the area, or that already have been recognised as important to that region. For instance, in the Kimberley region, the Precambrian rock types, features that illustrate their structural and metamorphic history, the Cainozoic ferricrete and laterite, and the landscape as related to geology, comprise the geological essentials of that region, and on the Nullarbor Plain, the Tertiary limestone, the coastal cliffs, the karst, the cave sedimentary deposits, the late Cainozoic surficial aeolian sand sheet, and wetlands would be identified (Brocx & Semeniuk 2010a, 2011b). In more detail, knowing the parent rocks, their structural style and history, and metamorphic grade of a terrane can point to the structure types (e.g., isoclinal folds), metamorphic minerals (e.g., biotite, pyroxene, garnet) and lithologies that can be expected. Specifically for coastal geoheritage, this step, at the largest scale, involves classification of the coast types developed by the five main coastal processes within a given region, and, at smaller scales, involves identifying smaller scale features particular to any coast within its regional setting.
Step 3 - allocate each of the components of the list, or ensembles of the components (developed at Step 2) to a conceptual category of geoheritage: Determine whether a given location is a reference site, a cultural site, a geohistorical site, or a modern active landscape so that comparisons in assessing levels of significance are undertaken within similar conceptual categories.

Step 4 - allocate the geologic features in the list to a specific scalar frame of reference: This is so that assessments of levels of (comparative) significance can be undertaken within similar scalar categories.

Step 5 - assess the level of geoheritage significance: Use of the definitions/criteria outlined earlier in the Thesis for each of the components of the list developed at Step 2 to assess significance. The next stage would be to locate the best examples, regardless of scale, of these features or of inter-related ensembles of features. Once the inventory of components and their level of significance of a study area are compiled, and enough geological features have been ranked as being of significance, or a few rank as being of high significance, sites of geoheritage significance can be proposed/proffered for geoconservation at a Regional, State, National or International level for one or a few of its components, or for the integrated ensemble of its components. If the latter, the area may qualify to be viewed as a geological park (or geopark).

Step 6 - determine what type and what level of geoconservation the area requires: After an assessment of the range, categories, inter-relationships, and level(s) of significance of the geological features has been carried out, the type and level of geoconservation or management the area, geosite, or geological feature that is required can be determined.

In summary, the use of the Geoheritage Tool-kit, whether applied site-specifically or area-specifically, or at the geological region scale, begins with identifying geological regions within which sites or areas are embedded, and then listing the geological essentials, or the main geological features that characterise that geological region, to develop a database for sites of geoheritage significance. The next stage is to locate good examples, regardless of scale, of these features, or of inter-related ensembles of features, and assess them according to significance criteria (Table 2.4 & Figure 2.3). The inventory of the geological essentials of a region forms the basis to identifying the sites of geoheritage significance.
**Chapter 8: Application of the Geoheritage Tool-kit to identify inter-related geological features at various scales for designating sites at the scale of a geopark or geosite: case studies from coastal Western Australia**

This Chapter provides case studies of eight areas (Figure 8.1). Four of these are at the large to regional scale and serve to identify areas that may be suitable to be designated and managed as geoparks. The other four areas are at the small, or site-specific scale, and serve to identify sites that may be utilised and managed as geosites.

The large to regional scale examples are the Kimberley Coast, King Sound and the tide-dominated delta of the Fitzroy River, the Leschenault Peninsula and its leeward estuarine lagoon, and the Walpole-Nornalup Inlet estuary. The small scale site-specific case studies are Willie Creek, north of Broome, Entrance Point at Broome, Point Leander at Dongara, and Muderup Rocks at south Cottesloe.

Publications, relevant to this Chapter, that are a result of this study and Thesis, are referred to as the basis for elaborating on the geology, geomorphology, and geoheritage values of the Kimberley Coast, King Sound and the Fitzroy River delta, the Leschenault Peninsula and Leschenault Inlet estuary, and the Walpole-Normalup Inlet Estuary. For more extensive descriptions of these coasts from the point of view of their geological content and geoheritage values see Brocx & Semeniuk (2011a, 2011b), Semeniuk & Brocx (2011), and Chapter 18 by Brocx & Semeniuk in Semeniuk et al. (2011).

The areas comprising the regional scale case studies are composed of a range of geological features and can be treated as geoparks. That is, conservation of these areas must be addressed at a large scale and in an integrated manner since they only provide a holistic expression of features of geoheritage significance when treated at the large scale. The small scale areas are treated as geosites and provide a holistic expression of features of geoheritage significance only at these smaller scales. The geosites cannot be viewed/treated at the large scale because the relevant features of the sites that are of geoheritage significance do not extend beyond 100 m in size.

**Application of the Geoheritage Tool-kit in coastal Western Australia: case studies at the regional to large scale**

Four case studies at the large to regional scale in Western Australia illustrate the use of the Geoheritage Tool-kit wherein inter-related geological features at various scales are identified and assessed as a basis for designating geoparks. The study areas are from north to south (Figure 8.1):

1. Kimberley Coast (Brocx & Semeniuk 2011b),
2. King Sound and the Fitzroy River tide-dominated delta (Semeniuk & Brocx, 2011);
3. Leschenault Peninsula and its leeward estuarine lagoon (Brocx & Semeniuk, 2011a);
4. Walpole-Normalup Inlet estuary (Semeniuk et al., 2011).

After the description of the geoheritage essentials of the various areas, Tables 8.1-8.4 describe and assess their key geological features in terms of type of site and its scale, category of feature (from Figure 2.6), significance of geological features, and rationale for assigning the level of significance.
1. The Kimberley Coast

The Kimberley Coast is a large-scale ria coast, with a well developed intricate indented rocky shoreline, cliffed coasts, local nearshore islands (archipelago), and a distinct suite of coastal sediments (Figures 8.2-8.9). It is set in a tropical climate that ranges from humid to semi-arid. In addition to its intrinsic geoheritage values, its unique geological and geomorphological features are found in an unspoiled wilderness setting (Figure 8.10) in which the ensemble of natural processes are still operating.

In terms of classification for comparative coastal geoheritage purposes, the Kimberley Coast can be assigned to several coastal types depending on location (see Chapter 6):

- **Type 1** landforms developed by the post-glacial marine inundation of pre-existing landforms where the primary pre-inundated landscape is still evident;
- **Type 2** landforms developed by marine inundation of pre-existing landforms and coastal erosion of the bedrock geology, or hinterland landforms;
- **Type 5** coastal landforms developed by marine inundation and sedimentary infilling;
- **Type 6** landforms wholly constructed by coastal sedimentary processes that have been active during the Holocene;
- **Type 7** landforms constructed by Holocene coastal sedimentary processes that have superimposed erosional features;
- **Type 8** biogenic coasts;
- **Type 11** Holocene depositional coasts recording sedimentary history, ocean history, climate history and sea-level history; and
- **Type 12** sea cliffs exposing (Precambrian) lithology, stratigraphic sequences and contacts, and structure.

The landscape, rivers and valleys form the architecture to the Kimberley coastal region. The landscape of the Kimberley region has been described by previous authors at a regional scale or at a reconnaissance level or as a background to geological studies, but not to any detail or emphasis for use in interpreting coastal landforms. For completeness they are cited here; they include Jutson (1950), Speck (1960), Speck et al. (1964), Mabbutt (1970), Jennings & Mabbutt (1977), and Pilgrim (1979).

The rias and cliffs of the Kimberley Coast are cut into Precambrian rocks: the sandstones and basalts of the Kimberley Basin that comprises the Kimberley Plateau and, in the southern areas, into folded sedimentary rocks and metamorphic rocks of the King Leopold Orogen (Myers & Hocking 1988; Griffin & Grey 1990a, 1990b; Griffin et al. 1993, Tyler & Griffin 1993; Hassan 2004). The rocks of the region are well exposed along the shore providing a global classroom (or global reference site) by which to study the region’s stratigraphy, structure, and lithology, i.e., internationally important for geoscience research and education. The coast, however, is not just a continuous rocky shore composed of cliffs, as it also has local sediment-filled gulfs and embayments, cliffs with benches, cliff shores fringed by mangroves, cliff shores with bouldery ribbons in the tidal zone, and stretches of beaches and, in the embayments, muddy tidal flats, spits, cheniers, tidal creeks cut into the tidal flats, and (embayment-head) alluvial fans (Semeniuk 2011). Locally, the coast is composed of algal reefs and coral reefs, beach rock, and various types of tempestites (Semeniuk 2011). The coastal forms in the Kimberley coastal region have been determined by a number of geological, geomorphological, and oceanographic features: 1. the lithology and structure of regional geology, 2. interfaces between major geological units, 3. marine inundation of onshore landforms, 4. the sizes, shapes and configuration of rivers, creeks, their tributaries, and other valley tracts in the region as controlled by the geology, and 5. local Holocene sedimentation such as mud accretion, and beach, spit, barrier and dune development (Figures 8.4 & 8.5).

Underlying patterns to hinterland landforms and to coastal forms developed from them are the horizontal nature of the dominant lithologies, the fault/fractures in the region, and the orogenic fold belt. Within the context of the sandstones and basalts that lithologically dominate the Kimberley region, structurally there are eight main determinants of landform expression of ridges, spurs, plateaux, ravines, and valleys:
1. the sandstone-dominated terrain of the inland Kimberley region, composed of relatively flat-lying lithologies, is essentially a dissected plateau locally with mesas;
2. the basalt-dominated terrain of the inland Kimberley region, composed of basalt, also is a dissected plateau locally with mesas;
3. the felspathic and haematitic sandstone terrain of the Yampi Formation, which forms a dissected rounded topography;
4. the warp (fold) axes that have resulted in the local doming of the plateau and in west-oriented drainage and northwest to north-oriented drainage;
5. major NW-oriented faults;
6. regional rhomboidal fractures, mainly in the sandstones, and thus NW, NE oriented smaller valley and ravines;
7. the King Leopold Orogen fold belt that results in WNW-oriented ridge-and-basin topography; and
8. geological/lithological contacts, and contacts between terranes, that result in NNE-oriented and N-oriented embayments.

The drainage basin systems and their seaward expression as ria coasts, together with the rocks cropping out at the coast, define three main sectors of the Kimberley Coast (Figures 8.4 & 8.5 from Brocx & Semeniuk 2011b):

Sector 1: the coast between Cape Dussejour and Cape Londonderry: dominated by sandstones;
Sector 2: the coast from Cape Londonderry to Collier Bay: dominated by sandstones, but also with outcrops of basalt, siltstone, and haematitic sandstone; and
Sector 3: the extension to the coast of the King Leopold orogenic fold belt.

Sector 1 is dominantly a straight coast cut mainly into the Warton Sandstone, with development of small ravines, small coastal indentations, and some embayments formed by medium rivers. Sector 2 is a highly indented coast cut mainly into the King Leopold Sandstone, as well as into the Carson Volcanics, Warton Sandstone and local Hart Dolerite, with development of macroscale to mesoscale embayments formed by large rivers and tide-dominated deltas and mesoscale embayments, as well as sections of straight coast with small ravines, small coastal indentations. Sector 3 is a highly indented coast formed by marine-inundation of the ridge-and-basin topography of the King Leopold Orogen comprised of a variety of folded formations (including the King Leopold Sandstone and Warton Sandstone), with development of mesoscale to macroscale embayments, as well as sections of straight coast with small ravines and coastal indentations. Local outcrops of volcanic rocks near Cape Londonderry and at Port Warrender provide smaller scale variations of coastal morphology to the main coastal patterns of Sectors 1 & 2 as shown in Figure 8.4.

In the context of the geology/geomorphology described above, there are eleven coastal forms occurring along the Kimberley Coast, some of which represent the types of rias in the region, ranging from marine-inundated fluvially incised valleys to marine-inundated erosional valleys, illustrating the scope of what is a *ria* and a *ria coast* in this Thesis; the coastal forms are (Figure 8.7):

1. large funnel shaped gulfs;
2. large narrow v-shaped gulfs;
3. large broad embayments;
4. medium-sized to small narrow v-shaped ravines and valleys;
5. medium-sized to small embayments and coves;
6. isolated inlets and lagoons;
7. rectilinear to rhomboidal intersecting embayment/inlet complexes;
8. archipelago-and-embayment complexes bordering the Kimberley Plateau;
9. archipelago-and-inlet complexes bordering the King Leopold Orogen;
10. straight rocky shores; and
11. scattered islands in an archipelago.

A selection of these coastal forms is illustrated in Figures 8.6 & 8.7.
Depending on the orientation and oceanographic aspect of these coastal forms, they experience a gradation of wave and tidal energy, and hence determine or influence the nature and style of sedimentary accumulations. They may be exposed to prevailing swell and wind waves and thus subject to high energy of waves and tides. They may be relatively protected from prevailing wave action and subject mainly to tidal currents. Or they may be fully protected from wave action and only inundated on the highest tide (at times of slack-water and near-slime-water) and thus oceanographically of low energy. The nature and style of sedimentary accumulations is also determined by how much sediment is delivered to or generated at the coast.

The coastal landforms, derived from marine inundation of the ancestral landforms, form the template for local Holocene sediment deposits that also contribute to coastal landform development through mud accretion on tidal flats, and beach, spit, barrier and dune development (Coastal Types 5, 6 & 7 of Chapter 6). The sedimentary deposits along the Kimberley Coast are described by Semeniuk (2011), and a summary list is provided below. The sedimentary deposits form natural packages that are grouped into eleven suites reflecting their coastal setting, sediment types therein, processes that developed them, and stratigraphy. The simplest stratigraphic packages are ordered in a general manner from coarsest sediment and high-energy-emplaced to the most fine grained deposits, i.e., from tempestites to mud tidal flat systems, relating to an energy spectrum. The exceptions to this list of simple stratigraphic packages are the ria and embayment systems and bar-and-lagoon systems, which, as noted above, are complex ensembles of sediments. The stratigraphic packages, from Semeniuk (2011), are:

1. tempestites;
2. block, boulder and gravel shore deposits;
3. high-tidal alluvial fans;
4. tombolos and cuspatate foreland deposits;
5. beach cove deposits;
6. barrier sand/gravel deposits;
7. beach-ridge deposits;
8. sand-and-mud tidal flat systems;
9. mud tidal flat systems;
10. ria and embayment systems; and
11. bar-and-lagoon systems.

Geologically important, and of geoheritage significance, there are three other types of Holocene coastal materials; these are:

1. fringing algal reefs;
2. fringing coral reefs; and
3. beach rock.

The Kimberley Coast presents numerous features of geoheritage significance: 1. with ~ 700 km of (simplified) coastal length, it presents the best and most extensive expression of ria morphology in Australia, and also one of the best developed globally; 2. the occurrence of the shore in a monsoonal subhumid/humid tropical macrotidal setting, with processes distinct to this setting; 3. as a tropical-climate ria system, in terms of size and morphology, it is globally unique; 4. the morphology of the shores, variable in form in response to the grain of the country (viz., the Kimberley Basin versus the King Leopold Orogen) and lithology; 5. variation of rocky shores along its length in terms of mesoscale shore types; 6. the sedimentary packages that occur in the region; 7. mangrove-lined rocky shores and embayed shores, with the latter also related to freshwater seepage; and 8. biogenic and diagenetic coasts. Illustrations of these features are presented in Figures 8.6, 8.7, 8.8 & 8.9.
In terms of its geoheritage essentials there are 19 features along the Kimberley Coast that are noteworthy; these are:

1. the extent that a ria coast is developed;
2. types of rias developed as related to geology;
3. types of rias developed at different scales;
4. Precambrian geology: geology, stratigraphy, transition of basin to orogen;
5. geomorphology expressed at the coast;
6. biogenic coasts (algal and coral reefs);
7. tempestites;
8. barrier sand/gravel deposits;
9. bar-and-lagoon deposits;
10. sedimentary sequences;
11. freshwater seepage and waterfalls;
12. key hydrodynamic features;
13. types of cliffs along rias and rocky shore geomorphology;
14. processes of cliff erosion;
15. salt weathering;
16. types of coasts;
17. diagenetic coasts;
18. key coastal outcrops; and
19. scenic vistas.

These features are described below in terms of their setting and geology and in terms of scale, geoheritage category, level of significance, and rationale for determining level of significance in Table 8.1.

Figure 8.11 summarises the geoheritage features of the Kimberley Coast, showing the categories of geoheritage sites in the area, a representative range of geological features at decreasing scale, and the assessment of significance of each of the geological essentials of the area.

High on the list of features of geoheritage significance along the Kimberley Coast (Table 8.1) is the extent that ria shores are developed. This is because, while there are other ria coasts elsewhere in Australia and globally (see review in Brocx & Semeniuk 2011b), the ria coast of the Kimberley region is globally an outstanding system in terms of its size and extent, its style of development, and its variability of geomorphic, stratigraphic, hydrological, hydrochemical, and diagenetic features.

To place the ria coastline of the Kimberley Coast in a comparative global perspective, Precambrian rocks globally, their localised occurrence along the coast, and the climate setting of the ria coasts (and fjords) are shown in Figure 8.12. It is noted that few rias (and fjords) are cut into coastal exposures of Precambrian rocks. A comparison of the size, extent, and plan-geometry of some rias and fjords of the world in comparison to the Kimberley Coast shows that the Kimberley Coast rias show the largest extent of ria coast globally (Figure 8.13).

Description and assessment of the geoheritage components of the Kimberley Coast are presented below.

In terms of the twelve coastal types described in Chapter 6, there are a variety of coastal types developed in the Kimberley region, as noted earlier, viz., Types 1, 2, 5, 6, 7, 8, 9 and 12 and, as an ensemble of coast types in the region, they comprise a Nationally-significant classroom for coastal development and classification, particularly for those coastal types that are intergradational. This aspect of the Kimberley Coast generally is a macroscale to mesoscale feature, and is assigned to the geoheritage category of modern landscapes and setting (active processes).
The ria coast developed along the Kimberley Coast is a megascale feature, assigned to the geoheritage category of modern landscapes and setting (active processes). The Kimberley Coast is the largest ria coast in the World, with an overall length of some 700 km, but unlike other ria coasts developed globally, this coast is cut into resistant Precambrian sandstone, with development of steep cliffs and shoreline bluffs. As such, it is a global classroom or global reference site, with International significance. The different types of rias developed along the Kimberley Coast, as related to geology, generally are megascale to macroscale features, also assigned to the geoheritage category of modern landscapes and setting (active processes). Within this single region, with (interrelated) geology of Precambrian basin to orogen, the Kimberley Coast presents a globally unique transverse coast where the King Leopold Orogen, comprising multiple lithologies, tight folds, faults, and fractures, all oriented transverse to the coast, crops out along the shore and, additionally, presents an adjoining coastal sector of marine-inundated fluvially-incised terrain. Unlike transverse coasts elsewhere globally (e.g., south-western Ireland), the transverse coast in the Kimberley region is developed on Precambrian folded rock. These tightly folded rocks are the foundation to a (pre-Holocene) ancestral ridge-and-basin geomorphology that, when inundated by the post-glacial marine transgression, has developed coastal landforms reflecting the orientation of the ridge-and-basin geomorphology, viz., ridges, spurs, razorback ridges, oriented narrow inlets, nearly isolated inlets, amongst others. The coastal landscapes themselves are globally unique in terms of their foundation geology, coastal landforms developed, styles of cliffs developed on various lithologies and various structural attitudes, and the large range of scales at which the coastal features are developed.

The two classic ria forms known globally and described in the literature have been assigned type locations in disparate areas (viz., transverse rias in the Adriatic Sea and south-western Ireland, and the marine inundated river valleys in north-western Spain). However, in the Kimberley region, both of these ria forms occur adjoining each other and, further, occur within the same general oceanographic setting with similar coastal processes, within a generally similar tropical climate, and a within a generally similar geology. This is a feature of International significance and, ideally, the Kimberley Coast, comprising coastal forms developed on the Kimberley Basin and King Leopold Orogen could be viewed as the global type location for ria shores, and could potentially be used as a global reference site.

The Kimberley Coast presents a variety of (river valley) rias developed at different scales and of different shapes. Some are fracture-and-fault controlled, varying from large gulfs to small embayments to small ravines, with orientations that reflect the conjugate fault-and-fracture patterns of the region that resulted from the weathering/erosion of the sandstone bedrock, and some are inundated, rounded hills and undulating terrain that resulted from the weathering/erosion of basaltic bedrock. This aspect of ria shores for the Kimberley Coast generally is a megascale to macroscale feature, and is also assigned to the geoheritage category of modern landscapes and setting (active processes), and could also potentially be used as global reference sites. With its expression of marine-inundated rivers, creeks, valley tracts, and ravines of various sizes (since all these marine-inundated valley forms are naturally inter-gradational and form an integrated network), the Kimberley Coast provides a standard of the range of shorelines in terms of shape, sizes, and coastal orientation, that can be assigned to ria coasts and, again, can be viewed as a global classroom or global reference site. It is a feature is of International significance.

The Kimberley Coast provides extensive exposure of Precambrian geology along its cliffs, which is an important feature in the region. This aspect of the Kimberley Coast is a megascale to macroscale feature, and is assigned to the category of geohistorical site. The Kimberley Coast presents well-exposed and extensive coastal cliff outcrops of Precambrian geology, that for over 700 km of general coastal length, and ~ 4000 km of more detailed measured coastal length, exhibit along the shore the sedimentary rocks and facies changes within the Kimberley Basin, volcanic rocks of the Kimberley Basin, as well as the structures and lithology of the King Leopold Orogen, and the geological transition from rocks of the mobile zone (King Leopold Orogen) to those of the Kimberley Basin. This excellent exposure and extent of exposure is a feature of International significance.
The geomorphology expressed at the coast also is another important aspect of the region. Many of these geomorphic features are well expressed along extensive coastal tracts involving several to tens of kilometres of coast and should be viewed as an ensemble of coastal forms along a single large coastal tract, rather than as site-specific localities. The range of geomorphology developed at the coast is partly due to the processes of coastal erosion and partly due to inundation of ancestral landforms. As such, fronting the sea, bordering the gulfs, framing the narrow inlets, or forming local islands, there are sandstone vertical cliffs and other types of sandstone steep shores, cliffs with boulder and scree aprons, plunging basaltic cliffs, coastally-located mesas, fretted coasts, two-layered and terraced islands and cliffs, and lithologically-determined platforms and benches [Edwards (1958) first recognised lithologically determined platforms as coastal forms in the Kimberley region along the shores of Yampi Sound in the Buccaneer Archipelago]. The various forms of geomorphic expression along the coast broadly conform to the three sectors of the Kimberley Coast. For example, the coastal tract of sea cliffs between Cape Dussejour and Cape Londonderry, Sector 1, shows an overall straight coast with fracture-controlled mesoscale to microscale ravines and indentations, and lithological control of coastal cliffs and benches, and is a particular type of coast specific to this region. The coast of Collier Bay, Yampi sound, and the Buccaneer Archipelago, Sector 3, shows a highly indented form corresponding to the seaward expression of the ridge-and-basin topography of the King Leopold Orogen. In Sector 3, because of the variable lithology and the structural attitude of the fold limbs, there are various coastal forms developed: rias grading to nearshore islands and rocky reefs and archipelagos; the southern shore of Collier Bay showing a highly indented mesoscale to microscale ria complex dominating the coast; the central north-west trending bay-dissecting peninsula of Talbot Bay showing a crenulate northern coast; the south-western shore of Cone Bay showing an extensive shoreline developed by steeply dipping rocks, oblique shears, and cross-fractures; and Round Hill area, northern Stokes Bay showing the contact between salt flats and rocky shore.

Some of the key geomorphic features along the Kimberley Coast illustrate examples of coastal forms that are particular to the Kimberley region. These include: partially sediment-filled embayment and digitate spur complex around Cape Dussejour; the bar-and-lagoon system between Cape Dussejour and Thurburn Bluff; the narrow v-shaped ravines formed by the bedrock fracture system 10 km south-west of Buckle Head; the two-layered, terraced cliffs formed by the Carson Volcanics and the Warton Sandstone cropping out at the coast in superposition (at Buckle Head, and 5 km NW of Seaplane Bay between Cape Dussejour and Cape Londonderry); Cape Bougainville (a highly dendritic/digitate ria coastal form with bauxite-capped plateau forming the shore and hinterland); the tide-dominated mud delta of the Lawley River; the tide-dominated sand-and-mud delta of the Drysdale River, with its ocean-facing cheniers and spits, the ria coast embayment complex of broad embayments and headland spits of Port Warrender; the peninsula of Pickering Point, the west coast peninsula of Walmesly Bay, and Bigge Island and the adjoining mainland as sites where there are rhomboidal, narrow v-shaped inlet systems formed by erosion of the bedrock fractures; the Mitchell Falls in the Mitchell River area where a riverine waterfall directly contacts with the marine environment at the head of the Mitchell River; the Prince Regent River coast with St Georges Basin and Mount Trafalgar as a large mesa bordering the Prince Regent River coastal complex; the coastal landscape of Prince Frederick Harbour in the Buccaneer Archipelago, featuring a “rock tombolo” attached to a mesa and separating/sheltering a large mangrove-vegetated tidal flat, the Talbot Bay ria system (the linear array of islands and peninsulae of the marine-inundated ridge-and-basin system of the rocks of the King Leopold Orogen).

Generally, the key geomorphic features described immediately above are megascale to macroscale features, and locally microscale features, and are assigned to the geoheritage category of modern landscapes and setting (active processes) and partly to geohistorical site, the former because it is extant and still being formed, the latter because some of the landforms are ancestral and manifest pre-Holocene morphology. The key geomorphic features could also potentially be used as global reference sites for ria coasts. They are of International to National to State-wide significance from the perspective of geomorphology and from the perspective of scenic vistas (see later).
The algal reefs along the Kimberley Coast are shore-fringing boundstones (term after Dunham 1962, referring to accretionary deposits of skeletal organisms that form rigid carbonate structures). The algal boundstone reefs are deposits that encrust rocky shores at low tidal levels. They form fringing pavements up to 100 m wide, extending seawards from the rocky shore cliff. Structurally, they comprise grossly-layered skeletal boundstones with numerous platy to irregular cavities. Biologically, they are composed mainly of calcareous algae, with scattered small corals, embedded bivalves, lithophagic bivalves, interlayered and encrusting serpulid worm tubes, other worm tubes, bryozoans, hydrozoans, and sponges.

Algal reefs have been documented elsewhere in the World but they are of different types and in different settings to those of the Kimberley Coast. For instance, in the Bermuda Platform, which is dominantly a coral reef environment, they form “cup reefs” that are isolated algal bioherms with depressed centres and raised rims (James 1983). In the Caribbean region generally they occur as “algal ridges” associated with coral reefs (Ady 1978; Tucker & Wright 1990; Bosence 1983a). Modern algal ridges and reefs composed of crustose algal frameworks (as distinct from concentrically encrusting rhodolith or rhodoid accumulations; Bosence 1983b, 1983c) have been described from the coralligène (in the Mediterranean), at St Croix (Virgin Islands, Caribbean), and the Pacific reefs, and branching frameworks have been described and illustrated from the maerl of the north-east Atlantic (Bosence 1983a). Many of the algal reefs are closely associated as a subfacies of coral reef complexes. The algal reefs of the Kimberley Coast stand distinct as being a fringing algal reef type that inhabits sandstone and basalt rocky shores, forming shore-parallel platforms/wedges, and further, these algal reefs are a phylogenetically complex bioenosis of algae and encrusting and lithophagic invertebrate fauna, rather than an accreted aggregation of crustose algae. Basso et al. (2009) documented algal rhodoliths on rocky shores of subtropical New Zealand but these are dominantly concentrically encrusting pisoliths and fruticose forms.

The fringing coral reefs also are shore-fringing boundstones. They encrust rocky shores at low tidal to subtidal levels. In these reefs, coral and calcareous algae have built fringing coralline structures extending seawards from the fringing algal reefs that were described above. Structurally, the coral reefs also are composed of grossly-layered skeletal boundstones with numerous platy to irregular cavities. Similar to algal reefs, biologically they are composed mainly of interlayered corals and calcareous algae (but dominated by corals), with embedded bivalves, lithophagic bivalves, and interlayered and encrusting serpulid worm tubes, other worm tubes, bryozoans, hydrozoans, and sponges.

The biogenic coasts of algal reefs and coral reefs in the Kimberley region are mesoscale to microscale features, and are assigned to the geohistorical category of modern landscapes and setting (active processes) and partly to the category of geohistorical site, the former because they are extant and still forming, the latter because there are earlier (Holocene) fossil forms buried in the stratigraphy of the deposits. While the algal reefs often form shore-fringing platforms along portions of the Kimberley Coast, their association with a narrow seaward periphery of coral biolithite is particularly important. Because algal reefs are globally uncommon as rocky shore fringing structures, the Kimberley Coast examples are Internationally significant. Bosence (1983c), for instance, illustrates algal reefs along rocky shores, as distinct from coral reef settings, only in few locations globally (viz., along the east coast of temperate climate Canada) and none in the tropical regions of the World.

Tempestites occur as high-tidal and supratidal deposits fringing the coast and as conglomerate and breccia buried as ribbons in beach, spit, and dune deposits. They are gravel-sized to boulder-sized deposits depending on composition. Those composed of corals, shell gravel, or shale-derived lithoclast are pebble- to cobble-sized. Those derived from beach rock slabs and sandstone cobble- to boulder-sized. The various types of tempestites in the region are mesoscale to microscale size features, and assigned to the geohistorical category of modern landscapes and setting (active processes). They are of International significance as modern sedimentary models of tropical zone deposits formed in a cyclone-influenced macrotidal coast where corals, shell gravel, reworked beach rock slabs, and local rocky shore derivatives form the source material.
Barrier sand/gravel deposits emanate from headlands and form barriers to some embayments and narrow ravines in the region, particularly in Sector 1. They are composed of sand, or gravel, or mixed sand and gravel. The gravel is derived from shell, coral, or from erosion of rocky cliffs (for instance, generating shale or fine sandstone prolate platy lithoclast pebbles). These barrier sand/gravel deposits, especially the lithoclast gravel barriers, are mesoscale to microscale features that are assigned to the geoheritage category of modern landscapes and setting (active processes). Gravel barriers (and gravelly shores) occur throughout the globe but are associated most commonly with formerly glaciated regions, tectonic coasts where streams deliver gravel to the shore, and wave-dominated rocky shores (Carter 1988; Carter & Orford 1993), e.g., Chesil Bank barring The Fleet (Carr & Blackley 1973), and the barrier barring Cuckmere Haven (Mortimore et al. 2001; Larkin 2006) both in England. However, the gravel barriers of the Kimberley Coast are specifically formed across narrow ravines cut into Precambrian rock in a tropical macrotidal setting or are reworked scree deposits (where they front the coast) and, as such, are globally uncommon and Internationally significant.

Bar-and-lagoon deposits occur along the Kimberley Coast, especially in Sector 1. Barriers composed of sand or sand and gravel are developed across narrow ravines and narrow embayments. Leeward of the barriers are lagoons that generally have filled with mud. The bar-and-lagoon deposits, especially where the barriers are formed across narrow ravines, are globally uncommon. Essentially, along the Kimberley Coast, the development of bar-and-lagoon systems in a setting of a tropical climate, macrotidal regime, and cyclone influence coast, barriers formed across narrow ravines and embayments cut into Precambrian rock are Internationally significant. These features are mesoscale to microscale, and assigned to the geoheritage category of modern landscapes and setting (active processes).

The ensemble of sedimentary sequences along the Kimberley Coast, located in gulfs, tide-dominated deltas, rias, and other sedimentary settings, range from cyclone-generated tempestites, to mud-dominated systems. Their associated stratigraphic packages, developed by macrotidal and tropical conditions represent a global classroom or global reference site that shows inter-relationship of morphology, and oceanographic factors such as tide-dominated or wave-dominated prevailing conditions, or cyclone generated conditions, sediment delivery, the dominance of gravel versus sand and mud and, as such, are Internationally significant. These sedimentary sequences are megascale to mesoscale features along the Kimberley Coast, and are assigned to the geoheritage category of modern landscapes and setting (active processes).

Freshwater discharges as seepages into the high-tidal coastal zone, into scree developed along the interface between basalt and sandstone, and as waterfalls (e.g., the King George River cliffs, Mitchell River, and Crocodile Creek, Buccaneer Archipelago) are widespread throughout the Kimberley Coast. The fractured bedrock of the inland Precambrian system functions as a major freshwater aquifer which discharges freshwater into the high-tidal environment, influencing diagenetic and ecological processes (the latter, specifically for mangroves). Commonly, such discharges are along the upper edge of a salt flat at its contact with rocky cliffs, but locally they appear within the salt flat. Freshwater seepages are mesoscale to microscale features, and are assigned to the geoheritage category of modern landscapes and setting (active processes). Freshwater discharging into scree along the interface between basalt and sandstone are Nationally significant features. Freshwater discharging from rivers, creeks, and rivulets, as waterfalls directly into the sea are Nationally significant features. For mangrove systems (Semeniuk 1983, 1985), in a tropical ria coastal setting, this style and extent of freshwater seepage is uncommon hydrological feature and is Internationally significant as a global classroom or global reference site.

The Kimberley Coast also exhibits some key hydrodynamic aspects, such as the “horizontal waterfalls” (Australian Heritage Council 2010; Brocx & Semeniuk 2011b). The “horizontal waterfalls” is a local area (Talbot Bay) within the ria complex of narrow inlets, parallel inlets, and serial narrow gaps cut into rocky ridges, developed on the King Leopold Orogen, in a macrotidal regime, where there is a lag of tidal water interchange between two parallel inlets and the open ocean developing water level differences of several metres across the gaps. This is an extraordinary tidal hydrodynamic feature because of the configuration of the ria shores and inlets, and is Internationally significant. The “horizontal waterfalls”, is a microscale feature, and is assigned to the geoheritage category of modern landscapes and waterscapes (active processes).
While there has been emphasis in this Thesis on ria form and types ofrias along the Kimberley coast, another important aspect of this setting is the types of cliffs along rias and rocky shores. There are, in fact, a variety of cliff types developed along the rocky shores, with this coastal geomorphology reflecting oceanographic processes, rock type, stratigraphic sequence, geological structure (viz., structural attitude), and the induration, weathered nature and coherence of the bedrock. Thus, for instance, exposure of the Precambrian rock sequence to wave, tidal and cyclone activity, and salt weathering in a tropical climate, results in a variety of shore types cut into the rock, and different structurally-oriented rocks result in plunging shores, rounded plunging shores, terraced shores, razor-back shores, “fretted” shores, “fretted” rock platforms, (vertical) cliff shores, platform-and-cliff shores, bouldery shores (with either rounded boulders, or rock slabs), rocky shores with cobble and pebble veneers (with rounded cobbles/pebbles, or platy cobbles/pebbles), and high-tidal platforms developed by salt-weathering. The range of rocky shores in this region results from the fact that the Kimberley Coast is so laterally extensive, and there is opportunity for a variety of Precambrian rock (of varying lithology and structural attitudes) to be exposed locally to the range of oceanographic processes in a generally similar climatic setting. This is a situation that does not occur elsewhere in Australia. For instance, in contrast, the Tertiary limestones of the Eucla Basin, exposed in cliffs along the coastal edge of the Nullarbor Plain, though a laterally extensive cliff-line, presents a limited lithology, all in a horizontal structural attitude (Figure 1.1F). Further, the cliffs along edge of the Nullarbor Plain are oriented parallel to latitude and front a wave-dominated microtidal ocean of relatively uniform processes which then generates a regionally relatively uniform coast type. Elsewhere the coast of Australia is too heterogeneous lithologically, i.e., without the relatively consistent bedrock, to express the coastal variability of cliff lines that might develop across smaller scale changing oceanographic conditions such as the Kimberley Coast. Examples of the variety of the cliff types along the Kimberley Coast are illustrated in Figure 8.9. The suite of rocky shore products, illustrating geomorphology and coastal form along the Kimberley Coast, show how coastal form is expressed in laterally variable cliffs and rocky shores and is a Nationally significant classroom for rocky shore geomorphology. The rocky shore geomorphology and features range in size from mesoscale to microscale and leptoscale. They are assigned to the geoheritage category of modern landscapes and setting (active processes) and (potentially) a global reference site for variability of cliffs as determined by lithology, attitude, and aspect.

The processes of cliff erosion along the Kimberley Coast also contribute to the significance of the area. The erosional style is specific to this region because of the tropical environment, the macrotidal environment, wave action, the lithologies, structures of the lithologies (such as fractures and jointing), and the structural attitude of the rocks. Sandstone, siltstone, and basalt exposed at the shore are actively undergoing erosion by mass wasting, undercutting of cliff faces, joint-block erosion, salt weathering, wave erosion, tidal current erosion, and bioerosion. The suite of processes-and-products is a Nationally significant classroom for erosion processes and erosional products. They are assigned to the geoheritage category of modern landscapes and setting (active processes) and as national reference sites for variability of cliff development as determined by lithology, attitude, and aspect.

Salt weathering is a component of coastal erosion in this tropical environment, especially along the contact of the salt flats and bedrock cliffs. Salt weathering forms high-tidal pavements at about level of the highest astronomical tide (HAT). These pavements can be cut into basalt, dolerite, laterite, sandstone, and steeply dipping rocks. Where cut into steeply dipping rocks, the pavements expose the strata edge-on across the high-tidal flat. Similar pavements produced by salt weathering have been described from the Pilbara Coast (Semeniuk 1996). In the Kimberley region, these high-tidal pavements, indicative of macrotidal environments, range in size from microscale to leptoscale. They are coastal geomorphic features of National geoheritage significance. They are assigned to the geoheritage category of modern landscapes and setting (active processes).

The Kimberley Coast also locally manifests diagenetic coasts, which are generally mesoscale to microscale features. Beach rock, for instance, occurs in numerous locations along the Kimberley Coast as shore-parallel indurated beach sediment in the tidal zone (as sand or shelly beach sand or beach gravel). Locally, beach rock can form dominate the tidal zone to the extent that it forms a beach-rock shore.
Diagenetic coasts in the Kimberley region are assigned to the geoheritage category of modern landscapes and setting (active processes). Such coastal types also occur along the Canning Coast and Pilbara Coast (Semeniuk 1996; 2008), but are not common throughout coastal mainland Australia. The diagenetic coasts (beach rock cemented ramps) along portions of the Kimberley Coast are Nationally significant.

Some of the prominent coastal outcrops along the Kimberley Coast include excellent exposures of sedimentary and volcanic rocks of the Kimberley Basin, and the rocks of the King Leopold Orogen. Examples include the cliffs of Warton Sandstone at Thurburn Bluff, at the entrance and gorge of the King George River, and Cape Rulhieres, outcrop of Carson Volcanics overlain by Warton Sandstone in the Raft Point area, at Buckle Head, and the Osborne Islands, outcrop of Carson Volcanics at Steep Island, cliffs in the King Leopold Sandstone at the Sale River, at Galley Point, and along the shores of Bigge Island, and outcrops of the Yampi Formation along cliffs between Eagle Point and Yule Entrance. Generally, the coastal outcrops are mesoscale to microscale features. They are assigned to the geoheritage category of geohistorical site, and are of National to State-wide significance.

2. King Sound and the delta of the Fitzroy River
King Sound and the fan-shaped tide-dominated delta of the Fitzroy River (Figure 8.14) present a unique situation globally (Semeniuk & Brocx 2011). The region has one of the largest tide ranges in the World, resides in a tropical monsoonal semiarid climate, hosts one of the World’s few large tide-dominated deltas, and globally records one of the most complicated stratigraphic sequences for tidal flats (Semeniuk 1980a, 1981a; Semeniuk & Brocx 2011). Moreover, in comparison to broadly similar other delta settings or funnel-shaped sedimentary accumulations elsewhere globally, King Sound and its tide-dominated delta are largely in a wilderness setting.

In terms of classification for comparative coastal geoheritage purposes (see Chapter 6), King Sound and its fan-shaped tide-dominated delta of the Fitzroy River is assigned to the King Sound Geological Region, and assigned to Coastal Type 7 and Coastal Type 11, i.e., a coast constructed by sedimentation with superimposed erosion, and a depositional coast recording Holocene history, respectively.

In terms of geological setting, King Sound resides at the boundary of the Kimberley Region and Canning Basin (cf. Brocx & Semeniuk 2011b; Semeniuk & Brocx 2011). The greater King Sound is longitudinally partitioned into western and eastern sub-basins by the NW-trending peninsulæ of Mesozoic rock. Though western King Sound is now funnel-shaped, as defined by the contour of MSL, its pre-Holocene shape was more irregular, with a number of embayments to its south. There were/are subsidiary lobate to rectangular to digitate smaller sub-basins that were/are sites of relative protection/shelter. In finer detail, the margins of King Sound are crenulate at the scale of 100–200 m because the edge of the funnel-shaped system is demarcated by east-west oriented linear dunes (Semeniuk 1981a; Semeniuk & Brocx 2011).

Within the depression of King Sound there is a variable Quaternary stratigraphy (Semeniuk 1980c). The sequence consists of Pleistocene Mowanjum Sand (the red sand unit), the Airport Creek Formation (a partially cemented Pleistocene tidal flat unit), the Double Nob Formation (a Pleistocene palaeosol), and the Holocene units of Christine Point Clay (an early Holocene grey mud formed under mangrove cover) and the Doctors Creek Formation (a shoaling sequence of tidal sand to muddy sand and interlayered mud and sand to mud formed in the latter Holocene).

Holocene sedimentation and erosion in King Sound followed several basin-filling and erosional episodes (Semeniuk 1980a, 1981a; Semeniuk & Brocx 2011; and Figure 8.15):
1. with rising sea level after the last glacial period, there was an extensive reworking of fine-grained sediment in the region and its shoreward transport, leading to filling of the southern parts of the King Sound embayment and its sub-basins with (mangrove-inhabited) mud, resulting in the accumulation of the Christine Point Clay some 7000 years ago, followed by an erosional episode;

2. in the middle to late Holocene, deltaic sedimentation resulted in a sedimentary lobe comprised of a sand-to-mud shoaling tidal sediment sequence, capped by mud (formed in a mangrove-inhabited lithotope), with delta-land accretion progressing from south to north; the deltaic landscape was dominated by tidally-oriented shoals whose internal stratigraphy is a basal sand to mud sequence; the leading edge of this accreting lobe comprises sand shoals of the interior of King Sound that form the stratigraphically basal sand of the deltaic sequence, and proximal parts of this accreting lobe are the sand-to-mud tidal sequences capped by alluvial sediments that occur to the south of King Sound;

3. concomitant with deltaic accumulation, mud in suspension was delivered beyond the northern margin of the accreting delta (whose margin is delineated by the basal sand) to the central and northern parts of King Sound, in advance of the accreting edge of the delta; this mud accumulated in the various relatively protected smaller sub-basins; these accumulations can be considered to be the distal parts of the delta and equivalent to prodelta muds in classic delta sedimentary patterns; and

4. throughout this history, the Fitzroy River deposited subaerial floodplain sediments that filled the alluvial valley tract in southern parts of King Sound; these cap the deltaic sediment sequence. In addition, with erosion cutting into linear dunes along middle to northern margins of King Sound, various spits and cheniers were formed from the eroding tips of the dunes (Jennings & Coventry 1973; Semeniuk 1982). Cheniers also developed on the eroding northern extremity of the central peninsula that faces wind waves, swell, and cyclones.

The delta of the Fitzroy River is a classic tide-dominated delta. The landforms comprise tidally oriented shoals and tidally oriented inter-shoal channel ways. The sequence of sand to mud is also classically deltaic (Morgan 1970) though the difference between the delta of the Fitzroy River and other tide-dominated deltas is that it is framed within a bedrock basin and thus was semi-enclosed, whereas other such deltas are open to the sea (e.g., the delta of the Ganges-Brahmaputra Rivers).

The geomorphology of the tidal flats today consists of wide low-tidal flats, underlain by sand or by pavements of partially cemented Pleistocene sediments, followed upslope in turn by narrow mid-tidal flats underlain by Christine Point Clay (with exposure of fossil mangrove stumps) or by modern mangrove-vegetated tidal mud, and extensive high tidal salt flats. Ramifying and meandering across the salt flats are tidal creek networks ranging in width from centimetres to hundreds of metres, and extending in length from tens of centimetres to several kilometres. Tidal creek geomorphology dominates the high tidal flats of King Sound, and is the determinant of tidal landforms.

Based on stratigraphic and aerial photographic evidence, tidal creek erosion has been interpreted to have been a long-term process (Jennings 1975; Semeniuk 1980b, 1982). Several other features reinforce the conclusions about erosion, these include (Semeniuk 1980b): nodules under the tidal flats; the imprint of (supratidal) vegetation roots on the substrate; and dieback of modern strandline terrestrial vegetation. The dominantly erosive nature of King Sound results in excellent exposures of Quaternary stratigraphy. Low tidal flats and lower banks of deeply incised tidal creeks expose the Airport Creek Formation, the Double Nob Formation, and the Christine Point Clay and their inter-relationships (Semeniuk 1980a). Deeply incised tidal creeks expose the Christine Point Clay and overlying Doctors Creek Formation, and their inter-relationships Semeniuk 1980a). Extensive areas of salt flat in surface layers are riddled with fine rootlet structures that are unlike the coarse root structures of mangrove environments. The modern analogue for fine rootlets are grasses on supratidal grassy plains. Such grasses have long since retreated from areas of the now salt flat, but the rootlet structures record the former supratidal conditions, showing that the present salt flats have been developed by sheet erosion of supratidal flats (Semeniuk 1980a,1981, 1982).
Over the Holocene there have been alternating episodes of sedimentation and erosion, with deposition of Christine Point Clay in the early Holocene (some 7000 years ago), followed by its large scale scouring, followed by deposition of shoaling tidal flat sediments of the Doctors Creek Formation, and then the present phase of large scale net erosion, with cliff, tidal creek, and sheet erosion (Semeniuk 1980b, 1982). This erosion provides a global classroom or global reference site for such processes on macrotidal tidal flats. In fact, the tidal landscapes of King Sound largely have been determined by tidal erosion, and in particular tidal creek erosion.

Tidal creeks begin their history in crevices of mud cracks and in time deepen, widen and extend their headwaters to landward, progressively evolving to become large and deep meandering systems (Semeniuk 1980b, 1982; and Figure 8.16). The array of mud cracks coupled with the tidal flat slope generates meandering channels which become entrenched and remain fixed in form through all stages of creek growth. Creeks continue to deepen/widen until the floor is deep enough to intersect the permanently waterlogged muds or sands at a depth where slumping is initiated, and there is a more rapid widening and deepening of the channels; creek cross-sections then change from a shallow v-shape to a deeper u-shape (Semeniuk 1980b, 1982). Thereafter, erosion is rapid, and creeks widen and deepen in time to form major tidal creek networks the size of Doctors Creek (stage 6 in Figure 8.16).

Across the tidal flats, groundwater increases in salinity from ~ 40,000 ppm at MSL to ~ 240,000 ppm near the upper edge of salt flats (Semeniuk 1980a, 1080b, 1981a). This salinity gradient transcends various mineral precipitation fields: carbonate is precipitating under tidal flats above MHWS, and gypsum is precipitating under tidal flats further upslope. Nodules of Mg-calcite, aragonite, dolomite, calcite (or their mixtures), often nucleated on crustacean skeletons, such as the mud lobster *Thalassina anomala* and the fiddler crab *Uca*, are imbedded in Holocene formations and related to the hypersaline groundwater. Nodules precipitated from hypersaline groundwater within Holocene formations can indicate the extent erosion has preceded as such nodules, originally formed under salt flats, are being exhumed along sea cliffs forming gravel layers (Semeniuk 1980a, 1080b, 1981a).

Fairbridge (1961) identified an important climatic and stratigraphic relationship of Quaternary red sand dunes bordering/underlying the Holocene tidal flat deposits, best developed on the western edge of the Doctors Creek embayment. Later, Jennings (1975) and Semeniuk (1980c, 1982) investigated the relationship of these red dunes to the tidal flat deposits, describing the history of the Holocene transgression into the dunes. In the light of the works of Fairbridge (1961), Jennings (1975) and Semeniuk (1980c, 1982), this area has become known internationally and is of International geoheritage significance. It will continue to be a site of stratigraphic and climatic research, as the basic work carried out by those authors is re-explored, refined, and amplified.

The red sand dunes descending stratigraphically below tidal flat sediments in this area also provide conduits for freshwater seepage that discharges under the salt flats, e.g., Jennings (1975) documented “dune ghosts” of vegetation surrounded by vegetation-free hypersaline salt flats, and Semeniuk (1980a) documented groundwater salinity diluted by this seepage within buried fingers of dune sand under the salt flats. The erosional patterns in King Sound influence mangrove ecology and zonation, with different mangrove responses related to cliff, sheet and tidal creek erosion, providing a model of coastal erosion and its relationship to mangrove habitats (Semeniuk 1980a, 1980b). While globally most mangrove areas are viewed as sites where mangrove habitation is linked to coastal accretion, King Sound was the first location where coastal erosion and mangrove ecology were described to provide insight into coastal erosion and mangrove responses. As such it stands as a global classroom or global reference site for mangrove ecology in relationship to macrotidal coastal erosion (geomorphic geodiversity).

The King Sound area hosts several stratigraphic type sections (Semeniuk 1980c), viz., Mowanjum Sand, Airport Creek Formation, Double Nob Formation, Christine Point Clay, and Doctors Creek Formation (Figure 8.17). The Doctors Creek embayment, as the stratigraphic type section for the Christine Point Clay (Semeniuk 1980c) at Christine Point, is the most southern occurrence of the sedimentary unit known as the “Big Swamp” complex of Woodroffe et al. (1985) and is an important Holocene climate, stratigraphic, and sedimentologic unit. The “Big Swamp” phase of northern
Australia records an early Holocene history of rapid sedimentation, with large mangrove forests, and humid climate, unlike that occurring today in the region. Embedded in this stratigraphic unit at Christine Point, therefore, is the history of this part of Australia in terms of sedimentation style, sedimentation rates, mangrove ecology, and climate.

Within King Sound, there are 12 geological features of geoheritage significance. Some of the key features include the Quaternary stratigraphy, with early Holocene gulf-filling mud formed under mangrove cover, followed by middle to late Holocene deltaic sedimentation, and the relationship between Pleistocene linear desert dunes and Holocene sediment are globally unique and provide important stratigraphic and climate history models. The principles underpinning the erosion styles and mechanisms of various types of erosion (sheet, cliff and tidal creek erosion) combining to develop tidal landscapes and influence (mangrove) ecological responses (illustrating tidal landscape evolution determining mangrove response, i.e., an example of geodiversity determining biodiversity response), is a unique global classroom or global reference site for such principles and processes. The high tidal muddy salt flats have hypersaline groundwater; responding to this, carbonate nodules of various mineralogy are precipitated. Locally, linear sand dunes discharge freshwater into the hypersaline flats. With erosion, there is widespread exposure of Holocene and Pleistocene stratigraphy, and development of spits and cheniers in specific portions of the coast.

The 12 geoheritage essentials in King Sound and the tide-dominated delta of the Fitzroy delta are:

1. tide-dominated delta of the Fitzroy River
2. principles of erosion (tidal creek erosion and formation of tidal landscapes)
3. carbonate nodules
4. Holocene stratigraphy
5. relationship between Pleistocene linear dunes and Holocene tidal flat sediment
6. Holocene stratigraphy at Christine Point
7. Pleistocene stratigraphy
8. exposure of Holocene mangrove stumps
9. spits and cheniers
10. mangroves in response to coastal development
11. freshwater seepage
12. stratigraphic type sections

The features comprising the “geoheritage essentials” of this area are described in Table 8.2 in terms of scale, geoheritage category, level of significance, and rationale for determining level of significance. Application of the Geoheritage Tool-kit to King Sound and the tide-dominated delta of the Fitzroy River is shown in Figure 8.18, which summarises the geoheritage features of King Sound and the tide-dominated delta of the Fitzroy River, showing the categories of geoheritage sites in the area, a representative range of geological features at decreasing scale, and the assessment of significance of each of the geological essentials of the area.

3. Leschenault Peninsula and its leeward estuarine lagoon

The Leschenault Peninsula, a retrograding dune barrier in south-western Australia, and its leeward estuarine lagoon (Figure 8.19), with a variety of geological and geomorphological features from large to small scale, and varying in significance from International to State-wide, provide another example of the application of the Geoheritage Tool-kit. The Leschenault Peninsula is the only Holocene linear dune barrier system in Western Australia and its leeward estuarine lagoon is one of four large estuaries located along the south-western coast of Western Australia (see Semeniuk et al. 2000a, 2010 for comparative detail). Selected key features of the stratigraphy, geomorphology, sea level history, diagenesis, and pedology of this area are presented in Figure 8.20.

In terms of classification for comparative coastal geoheritage purposes, the Leschenault Peninsula and its leeward lagoon are assigned to the Perth Basin Geological Region, and assigned to Coastal Type 7 and Coastal Type 11, i.e., a coast constructed by sedimentation with superimposed erosion, and a depositional coast recording Holocene history, respectively.
The text below describing the Leschenault Peninsula and its leeward estuarine lagoon, in terms of its geology, geomorphology and active processes, draws only on the essential patterns of this barrier and estuarine system from the published literature. The dune barrier is located in a subhumid climate (Semeniuk and Meagher 1981a). The barrier coast faces the open Indian Ocean, with swell and wind waves directly impinging on the shore without offshore barriers perturbing, dissipating, or dampening the wave fields; tides are microtidal (Searle and Semeniuk 1985). For winter storms that derive from northwest, the estuarine lagoon has a long fetch to generate storm waves along the length of the estuarine lagoon.

The Leschenault Peninsula is a linear retrograding dune barrier, and is the southern part of the Leschenault-Preston Barrier (Semeniuk 1996) that formed during the post-glacial transgression when sea level reached near its present position in the Holocene ~ 7000 years ago (Semeniuk et al. 2000a). The initial, longer, more extensive, early Holocene barrier (75 km long, and approximately 0.5-1.5 km wide) formed because, unlike the rest of coastal south-western Australia, which is dominated by lines of offshore limestone islands, submerged ridges and reefs, associated onshore cuspate forelands and other sandy accumulations (formed leeward of the discontinuous and perforated offshore aeolian limestone barrier), and limestone rocky shores (Searle and Semeniuk 1985), the coast between Preston and Leschenault Peninsula offshore is shelter-free (i.e. without offshore limestone islands, ridges, and reefs), and subject directly to swell and wind waves (Searle and Semeniuk 1985). As such, instead of discrete cuspate forelands and limestone rocky shores, that typify the rest of south-western Australia’s shores, the coast has developed this extensive linear barrier.

The Leschenault Peninsula dune barrier, 15 km long, 15-30 m high, at the southern end of the Leschenault-Preston Barrier, is narrow, generally 0.5-1.0 km wide, and composed of overlapping eastward migrating parabolic dunes in various stages of mobility and fixation (Figures 8.20A, 8.20B, 8.20C & 8.20B). The gradation in time in landscape-and-vegetation evolution of these dunes are: mobile parabolic dunes, grading to fixed parabolic dunes with heath cover and incipient to weakly developed humic soils, to (naturally) geomorphically degraded parabolic dunes with forest cover and strongly developed but thin humic soils, to (naturally) geomorphically degraded undulating plains and plains with a woodland cover of tuart trees (*Eucalyptus gomphocephala*) and strongly developed thick humic soils (Figure 8.20A; Semeniuk and Meagher 1981a).

The stratigraphy of the barrier is complex (Figure 8.20C), reflecting a complex Holocene sea level history and barrier development with a sea level ~2 m AHD between 7000 and 3500 years BP, a sea level +3-4 m AHD some 3500-2000 years BP, and with a sea level falling to present level from 2000 years BP to the present (Semeniuk 1985), the result of local tectonism (Semeniuk and Searle 1986). A sheet of calcrete is forming in the zone of capillary rise above the modern water table (Figure 8.20D), induced by plant extraction of groundwater, leaving a residue of fine-grained calcite (around the tuart tree root hairs) that accumulates and coalesces to form mottles, and then (coalescing of mottles to form) massive calcrete, capped by laminar calcrete (Semeniuk and Meagher 1981b). Wind excavation of sand in the bowls of the parabolic dunes exposes the calcrete sheet, which forms a floor to the parabolic dune bowl. Plains with Tuart woodlands develop sheets of calcrete, while copses of isolated tuart stands develop lenses of calcrete. While this copse versus woodland/forest association is present on the Leschenault Peninsula, it is also reflective of a climate gradient: Tuart forests and woodlands predominate in humid climates and develop sheets of calcrete in the zone of capillary rise, while copses and isolated stands of tuarts in less humid climates develop lenses of calcrete in the zone of capillary rise (Semeniuk 1986a). Since the level of the water table under Leschenault Peninsula is and has been related to the position of MSL, then calcrete formed earlier in the Holocene under different levels of MSL and different heights of the water table is at lower or higher stratigraphic levels than the modern calcrete sheet. Further, calcrete occurs as lenses at these different stratigraphic levels, indicating that the Tuarts earlier in the Holocene formed copse vegetation formations and not woodlands and forests, thus signalling a different climate. These higher or lower stratigraphic level calcrete lenses have been used to reconstruct Holocene climate (Semeniuk and Searle 1985; Semeniuk 1986a).
Periodically, major storms and cyclones impact on the dune barrier, up-rooting the large trees and in the process locally ripping up the calcrete sheet within which their roots are embedded, creating a depression in the soil sheet. Later filling of the depression by sheet wash and fragments of calcrete develops a lens of calcrete breccia floatstone (Semeniuk 1986b). This process, on-going during the later Holocene, has developed isolated lenses of the calcrete breccia floatstone within the soils underlying the woodland plains (Figure 8.20E).

In the core of the dune barrier there is a “shoestring” or prism of freshwater bordered to the sea and to the estuary by saline water, with an inclined saline water / freshwater interface on both sides. Freshwater discharges by seepage to the sea shore resulting in the formation of beach rock (Semeniuk and Searle 1985), and to the estuary shore resulting in ecological responses (Cresswell 2000; Pen et al. 2000; Semeniuk et al. 2000b), calcitisation of estuarine plant roots by encrustation and permineralisation, and precipitation of calcitic laminae (Semeniuk 2010).

Beach rock, formed at the shoreline of the seaward edge of the barrier with time-staggered coastal retreat during periodic storms and cyclones, is left stranded as a submerged ridge or band of cemented sand (rock) off shore from the barrier (Figure 8.20B). Successive periods of formation of beach rock, and retreat of the barrier during storms, has left a series of shore-parallel bands and ridges of this rock reflecting the various former positions of the shoreline of the retreating dune barrier (Semeniuk and Searle 1987).

The Leschenault Inlet estuary, leeward of the dune barrier, is an elongate shore-parallel, shallow water estuarine lagoon with distinctive patterns of bathymetry and geomorphology, framed to the east by the Mandurah-Eaton Ridge (a Pleistocene quartz sand ridge; Semeniuk 1997), to the west by the Holocene dune barrier, and to the south by two deltas (Semeniuk 2000; Semeniuk et al. 2000a). One delta is tide-dominated (the Preston River Delta); the other overall is fluvial-dominated but asymmetric, with the southern part fluvial-dominated, and the northern partly storm-developed (the Collie River Delta).

The estuarine lagoon is diurnally microtidal, wave-dominated and wind-current driven. Estuarine waters are annually poikilosaline, alternating between brackish/marine salinity in winter and marine salinity in summer (Wurm and Semeniuk 2000).

At the large scale, stratigraphic relationships within the system are relatively simple (Semeniuk 2000). Estuarine sediments to the east onlap the Pleistocene quartz sand ridge, and Holocene dune barrier sands encroach over estuarine sediments to the west. Sedimentary patterns are underpinned by geomorphology and bathymetry, and linked to the lithologic nature of the dune terrain bordering the lagoon, as well as the nature of shorelines and the reworking of sources and hydrodynamics; with muddy sediments accumulating in deeper water basins and semi-sheltered environments, and sand accumulating on exposed platforms, dune margins, or in deltas (Pen et al. 2000). There are facies changes in the estuary from east to west, dependent on the source of shore sand, the bathymetry, and facies changes from south to north, from delta-dominated in the south to shallow mud flat dominated in the north (where south-westerly winds have carried mud in suspension to north to form in a large accumulation) (Semeniuk 2000). Small scale geomorphology and stratigraphic relationships along the dune barrier margin with the estuary are more complex, with spits, cheniers, pockets of mud in dune finger corridors, aprons of sand around the parabolic dunes that have encroached into the estuary, and interfingering of the dune sand with estuarine sediment (Semeniuk 2000).

As noted above, freshwater discharges from the barrier into the estuary form shore seepages, which are important for shore vegetation and fauna (Cresswell 2000). In one case, the freshwater seepage sustains a stand of mangroves, Avicennia marina (Semeniuk et al. 2000b).

Leschenault Inlet estuary is unique in southwestern Australia for several reasons. Formed behind a shore-parallel dune barrier, and wholly Holocene in age, its estuarine geomorphology and hydrologic structure are different to other local estuaries such as the Swan River Estuary and the Peel-Harvey Estuary (Semeniuk et al. 2000a). The estuary does not represent a classic and simple river-to-sea transition, but has rivers entering at the southern end of the long north-south oriented lagoon that had formed by marine processes rather than fluvial erosion.
Leschenault Inlet estuary has also had a complicated Holocene sea level history, resulting in complexity of its shores. Its western shore is further complicated as parabolic dunes encroach into the estuary, producing a varied assemblage of shore types and stratigraphic/hydrologic situations. The complex of shores and wetland types peripheral to the estuary support a variety of fringing vegetation assemblages as linked to shoreline geomorphology, stratigraphy, hydrology and hydrochemistry (Pen et al. 2000). Consequently, Leschenault Inlet estuary is a classic area for studies of how geodiversity underpins both local alpha biodiversity and beta biodiversity (cf. Whittaker 1972) and the ecology of estuarine peripheral vegetation. In this context, the system ranks as one of the most significant in southern and south-western Australia (Table 4 in Pen et al 2000). Through its proximity to the Leeuwin Current, the estuary also supports the most southern occurrence in Western Australia of the mangrove *Avicennia marina*, and the array of landforms and vegetation in and around the estuary as related to bathymetry, geomorphic setting and habitats, combine to create an important class room for Holocene estuarine shore palynology (Semeniuk et al. 2000c). Revets (2000) documented a rich (neo) palaeontological assemblage of Holocene foraminifera in the Leschenault Inlet estuary with a Fisher alpha index of 30.47 for the whole estuary. At one location opposite the Collie River delta, on a shallow water muddy sand platform, Revets (2000) found the richest biodiversity of (neo) palaeontological foraminiferal assemblage globally, with a Fisher alpha index of 31.87 – essentially the most species-rich assemblage of foraminifera in any estuary in the world.

For the Leschenault Peninsula area and its associated estuarine lagoon, there are many features that comprise its geoheritage essentials. Whereas there are linear barriers and linear lagoons elsewhere in Australia (e.g., the Younghusband Peninsula and its lagoon, The Coorong; (von der Borch and Lock 1979; Geddes & Butler 1984; Murray-Wallace et al. 1999) this linear retrograding dune barrier sheltering a linear estuarine lagoon is unique in Western Australia. It is wholly Holocene in age. By contrast, the coastal barriers of the Coorong to Mount Gambier Coastal Plain (e.g., the Younghusband Peninsula), though Holocene linear barriers, appear to have a core of Pleistocene limestone (Belperio 1995; Murray-Wallace et al. 1999). Additionally, because of the history of relative MSL, tuart developed calcrete, and mobile parabolic dunes interfacing with the estuary, the Leschenault Peninsula and its associated lagoon has developed a range of geomorphic, stratigraphic, hydrological, hydrochemical, and digenetic features distinctive and Internationally and/or Nationally unique to this system.

The Leschenault Peninsula and its leeward estuarine lagoon also have several type locations for Holocene stratigraphic units, viz., members within the Safety Bay Sand (the Burrangenup Member, the Rosamel Member, the Vittoria Member, the Koombana Beach Rock, the Binningup Calcrete), and the estuarine Leschenault Formation (Semeniuk 1983).

Drawing on the work of Semeniuk (1980a, 1985a, 1986c), Semeniuk & Meagher (1981a, 1981b) and Brocx & Semeniuk (2011a), there are 22 geological features of geoheritage significance in this area. Some of the key features include: an active parabolic dune landscape, retreating on its seaward edge and encroaching into the estuary; an interface between dunes and estuary that is the most complex sedimentologically, hydrologically, and ecologically in Western Australia; a stratigraphy that records a complex Holocene sea level history; barrier retreat that is recorded by parallel strips of submerged beach rock; a thin sheet of calcrete forming above the water table; and the distinctive and complex estuarine shore stratigraphy including calcitisation of sea rush roots under the high tidal flat. The 22 features in the area are:

1. linear retrograding Holocene dune barrier in south-western Australia
2. active parabolic dunes within the barrier
3. gradational range of landscapes from active mobile dune to undulating plain
4. calcrete forming in the modern zone of capillary rise
5. lenses of calcrete at high stratigraphic levels
6. calcrete exposed in deflation bowls of parabolic dunes
7. calcrete breccia floatstone
8. beach rock forming in the tidal zone
9. stranded beach rock forming submerged shore-parallel bands and ridges
10. complex stratigraphy of the dune barrier
11. Holocene sea level history recorded in the stratigraphy
12. complex of shorelines and stratigraphy along the dune/estuary interface
13. freshwater seepage along the dune/estuary interface and complex ecology
14. a prominent mangrove stand developed along the dune/estuary interface
15. estuary shore landforms along the western estuary shore, graded south to north
16. calcite encrustation of sea rush roots in the tidal zone
17. rich biodiversity of Holocene estuarine foraminifera
18. well-documented Holocene palynological record as a model for estuaries
19. north-south and east-west patterns in sediments and stratigraphy of the estuary
20. an intra-estuarine delta
21. peripheral wetlands along western and eastern estuary margin
22. stratigraphic type sections

These features are described in terms of scale, geoheritage category, level of significance, and rationale for determining level of significance in Table 8.3. Application of the Geoheritage tool-kit to the Leschenault Peninsula and its leeward estuarine lagoon is illustrated in Figure 8.21 where the categories of sites of geoheritage significance are identified, key selected features at the various scales are provided as examples, and the essential features are graded as to their level of significance.

Figure 8.21 summarises the geoheritage features of Leschenault Peninsula and its leeward estuarine lagoon, showing the categories of geoheritage sites in the area, a representative range of geological features at decreasing scale, and the assessment of significance of each of the geological essentials of the area.

4. The Walpole-Nornalup Inlet estuary
The Walpole-Nornalup Inlet estuary in southern Western Australia is a twin-basin ria estuary in southern Western Australia (Figure 8.22). It is set in a subtropical (near-temperate) humid climate, and in the most humid part of the State.

In terms of classification for comparative coastal geoheritage purposes, the Walpole-Nornalup Inlet estuary is assigned to the geological region of Albany-Fraser Orogen/Bremer Basin/Yilgarn Craton, and in terms of coastal types to Coastal Type 7 and Coastal Type 11, i.e., a coast constructed by sedimentation with superimposed erosion, and a depositional coast recording Holocene history, respectively.

The Precambrian rock sequences surrounding the Walpole-Nornalup Inlet Estuary are Proterozoic gneissic rocks of the Nornalup Complex, occurring only in the Walpole/Nornalup area (Geological Survey of Western Australia 1975; Wilde & Low 1978; Wilde & Walker 1984; Wilde et al. 1996; and Figure 8.23). They are an essential feature of the geology of this area, showing lithology of the Albany-Fraser Orogen, its metamorphic grade in this area, and its regional contextual relationship to batholiths (Semeniuk et al. 2011). Well-exposed outcrops within the Nornalup Complex generally are scattered, as the hinterland terrain is deeply weathered, but these rocks are well-exposed along the wave-washed coast, where they provide good outcrops for structural, lithological and textural analyses.

The gneissic rocks of the Nornalup Complex have a large-scale structure, lithologic layering, and grain that, through weathering and erosion, have controlled the estuarine form (i.e., the morphology of the estuary; Semeniuk et al. 2011). The east-west orientation of Walpole Inlet and the tapering extremities of Nornalup Inlet in part reflect this grain. By weathering and erosion, the Precambrian rocks have developed into an array of high-relief hills and monadnocks, landforms that underpin the form of Walpole–Nornalup Inlet and that have made Walpole–Nornalup Inlet different to the other estuaries of southern Western Australia in form and shores.
The Walpole–Nornalup Inlet Estuary is a twin-basin ria estuary in a longitudinal sense (Figure 8.22), and this is unusual for an estuary in Western Australia (Brocx & Semeniuk 2009b; Semeniuk et al. 2011). That is, it is a twin basin along the length of the drainage line, and not a twin basin formed by internal segmentation (Isla 1995) which commonly occurs in elongated (estuarine) coastal lagoons. The twin-basin nature of the Estuary, with a narrow change channel between the Walpole Inlet basin and the Nornalup Inlet basin, and a tidal channel between the Nornalup Inlet basin and the ocean provides a complex hydrodynamic setting. When this is compounded by the fresh-water input from the rivers, it results in a hydrodynamically and hydrochemically unusual estuary. Within the estuarine there is a unique geological and geomorphological feature, a “rock tombolo” composed of Tertiary rock (the Coalmine Beach Peninsula of Semeniuk et al. 2011).

The high rainfall setting in this region appears to have been in existence for a considerable time, at least since the Tertiary and continuing into the Quaternary. Consequently, the Walpole–Nornalup area hosts the products of such a climate: thorough weathering of bedrock yielding a surficial sheet of quartz breccia and quartz grit, coarse quartz sand blankets, downslope deposition of sediments derived from the intense bedrock weathering (the various grades of sand, and clay), near in situ colluvial deposits, and lowland peat deposits. The Tertiary sedimentation, as valley fills, and as colluvial deposits, followed by erosion, has resulted in a multitude of sedimentary sequences occurring now as valley fills, hill-top residual occurrences of valley fills, cliff exposures, and as colluvial deposits.

For a relatively small area (15 km x 15 km), the Walpole-Nornalup area contains a wide range of Quaternary stratigraphic sequences (Figure 8.24). This is because of the high relief of the Precambrian rock terrain, the high rainfall setting, the variability of upland types, the range of rivers and their deltas located in different hydrodynamic settings, the coastal dune and desert dune history of this region, and the local sea-level history. The Quaternary stratigraphic sequences are variable depending on depositional setting, geomorphic setting, and origin, viz., deltaic sequences of the Deep River Delta, the Frankland River Delta, and the Walpole River Delta, the estuarine lowland sequences, the paluslopes bordering the estuary, the sands filling the valley tracts, the coastal dune sequences under the barrier, sediments underlying the tidal delta, and the range of shoreline sediments derived from varying uplands bordering the estuary.

The Coalmine Beach area exhibits significant Tertiary and Quaternary stratigraphy (Figure 8.25). For instance, in contrast to other areas of the exposures of sedimentary rocks of the Tertiary Werillup Formation and other units in the Tertiary Plantagenet Group (Geological Survey of WA 1990), which are either more wave exposed, or occurring in weathered state inland, the cliffs occurring at Coalmine Beach are semi-protected and partly wave-washed. They provide good exposure of the most western occurrence of the Werillup Formation (of lignite and overlying sandstone, sand, and clay), as well as contacts and relationships with overlying Tertiary and Quaternary sediments.

There are various Quaternary landforms within the Walpole–Nornalup Inlet Estuary area that reflect the nature of the parent terrain, the climate, and the oceanographic setting. These landforms include the weathered/eroded high-relief terrain of Precambrian rocks, the fluvial valley tracts, the barrier dune (Bellanger Barrier), the parabolic dunes within the Bellanger Barrier, the various estuarine coast types, and deltaic landforms. Figure 8.26 shows the range of landforms in the estuarine region.

Many of the rivers in coastal zones of Western Australia are deflected from orthogonally entering the sea by a Quaternary barrier (Holocene or Pleistocene ridge). The Frankland River presents a different situation for such river deflections. This river, in descending from the Yilgarn Plateau and Ravensthorpe Ramp (Semeniuk et al. 2011), crosses the southern part of the Western Australian continent in a north-to-south direction, but in the Walpole–Nornalup Inlet area it is deflected into an east-to-west direction (Figure 8.22).
The Walpole–Nornalup area presents an interesting assemblage of coastal dune landforms showing variable relationship of wind to parabolic dune orientation. Figure 8.27 shows that, for three of the southern coastal estuaries, the dune barriers sheltering the estuaries from the Southern Ocean have parabolic dunes consistently oriented in a SW-NE direction aligned with the summer sea breezes, whereas for the Bellanger Barrier in the Walpole–Nornalup area, the dunes vary from SW-NE to SE-NW, changing in size and orientation in response to wind speed and wind direction (Semeniuk et al. 2011).

The Walpole–Nornalup Inlet Estuary residing in a complex geological system has a corresponding complex of estuary shore landforms. The estuary is bordered by Precambrian rocks that form the foundation to estuarine form; it has a headland of Precambrian rock. The estuary has a barrier of Quaternary dunes whose northern shore contributes to the estuarine form and to sedimentation. There is a “rock tombolo” of Tertiary sedimentary rock in the Coalmine Beach area (the Coalmine Beach Peninsula; Figure 8.22), and a similar buried “rock tombolo” underlying the Quaternary barrier. The estuary has three deltas, all different in form and sedimentary sequence because of their river sizes, volume of sediment being delivered, and hydrodynamic setting. It is locally bordered by Quaternary limestone shores. There is a widespread quartz sand sheet that blankets the whole area. And it has had a variable sea-level history.

The Walpole–Nornalup Inlet Estuary also has a complex and unique stratigraphy along its shores. Given the complexity of shore types described above, given the high rainfall setting of the region, with the highest rainfall in the State centred on the Walpole coastal area, and given that mean sea level has been higher in the recent past, there is a complex and unique stratigraphy to this estuary. It ranges from sequences deriving from the three types of deltas, that of the estuarine lowlands, stratigraphic sequences occurring on steep shores that border Precambrian rock terrain, stratigraphic sequences occurring on moderately sloping shores that border areas of quartz sand, those bordering the barrier dunes, those where estuarine mud has been delivered to the shore to interact and mix with the primary stratigraphy of the shore, as well as limestone shores, rocky shores cut into Precambrian rock, and those cut into Tertiary sequences. Where there are specific hydrological processes operating because of the stratigraphic sequence, peat may be accumulating. In fact, many of the stratigraphic sequences in the Walpole–Nornalup Inlet area are peat-capped, including the deltaic sequences.

The complex stratigraphy of the shores of the Estuary is important for a second reason – the stratigraphy functions as a series of small-scale aquifers, aquatards, and aquicludes to create a complex hydrological system along the shores (Semeniuk et al. 2011). Stratigraphy underpins hydrology, and hence there is a strong relationship between stratigraphy and hydrology – this is particularly amplified in the Walpole–Nornalup Inlet area because of the high rainfall setting which results in direct meteoric input into the stratigraphy, and because of runoff and seepages. There is interaction along the estuarine shore of aquifers, aquatards, and aquicludes with rainwater, discharge from uplands of freshwater, artesian upwelling of freshwater, and estuary-derived seawater or brackish water along the immediate shoreline. The hydrology thus is extremely complicated. The resulting hydrochemistry also is complex (Semeniuk et al. 2011).

As such, depending on hinterland geology, aspect, and hydrodynamic setting, the estuary has developed a wide range of shores from cliffs, to steep shores, to low-gradient shores, underlain by rock, or boulders, gravels, sand, muddy sand and mud, and with variable hydrologic and hydrochemical function (Figure 8.28). For instance, Figure 29 shows contrasting stratigraphy along the estuarine shore with contrasting hydrochemical effect. With this complex geological setting, the estuary, in fact, has the most complex of estuarine shores in the Western Australia. This is also reflected in the range of peripheral vegetation inhabiting the shore (cf. Semeniuk & Semeniuk 1990, Pen et al. 2000). Given the range of geological settings along the shore of the Estuary, it can be expected that there will be a larger range of smaller-scale shore types. In terms of estuaries along the southern coast of Western Australia, Broke Inlet, Irwin Inlet, and Wilson Inlet have a much simpler assemblage of shore types compared to the Walpole–Nornalup Inlet Estuary (Semeniuk et al. 2011).
The deltas within the Walpole–Nornalup Inlet Estuary have been termed by Semeniuk et al. (2011) intra-estuarine deltas. The Walpole–Nornalup Inlet Estuary provides the best example of occurrence, variation, size of development and stratigraphy of intra-estuarine deltas in Western Australia. Semeniuk et al. (2011) show that for the four estuaries along the southern coast of Western Australia, it is the Walpole–Nornalup Inlet Estuary that has the largest numbers of rivers and creeks that enter an estuarine water body. Figures 30, 31 & 32 illustrate features of the two largest deltas in the Walpole–Nornalup Inlet Estuary, viz., the Deep River Delta and the Frankland River Delta.

The Walpole–Nornalup Inlet Estuary also provides examples of internal variation of intra-estuarine deltas in terms of their asymmetry, heterogeneity, and polygeneity (Semeniuk et al. 2011). The rivers and creeks within Walpole–Nornalup Inlet enter the estuary in different parts of the basin, with different amounts of sediment delivered, and different degrees of protection from wave energy. The deltas have responded to the hydrodynamic setting by constructing different types of deltas and different landforms within the delta. Wind direction, fetch, exposure to waves, and the style of sedimentary accumulation has resulted in varying degrees of asymmetry, heterogeneity, and polygeneity in the deltas in Walpole–Nornalup Inlet. Globally, deltas would be classified as fluvial-dominated, wave-dominated, or tide-dominated, according to shape developed in their setting, as the hydrodynamic environment determines the form of the delta itself (Galloway 1975; Coleman 1976; Reineck & Singh 1980). This global classification of deltas and the gradations between the three end-members is quite workable in open coastal situations, as the receiving basin for the deltaic sediments is the ocean and, for a given sector of coast where the delta might be located there is a spatially and temporally prevailing oceanic hydrodynamic setting. As a result, deltas in open coastal settings tend to be one of the three types, or gradations between the three end-members. Deltas developed within closed estuarine basins present complications to the delta classification because, unlike open oceanic environments, closed estuaries do not have a consistent hydrodynamic environment across the length and breadth of the basin, particularly if they are irregularly shaped such as the Walpole–Nornalup Inlet Estuary. The classification of the intra-estuarine deltas of the Walpole-Nornalup Inlet Estuary is shown in Figure 8.33.

In the Walpole-Nornalup Inlet Estuary, different intra-estuarine deltas are located in different energy regimes, and exhibit geomorphic and stratigraphic asymmetry, geomorphic and stratigraphic heterogeneity, and polygeneity, i.e., different parts of the delta have different origins (Semeniuk et al. 2011; and Figure 8.34). The Walpole River Delta is asymmetrical in that it has a greater extent of accretion on its northern deltaic plain. The Deep River Delta is markedly asymmetrical in sedimentation style and in development of deltaic landforms, with bar-and-lagoon sedimentation to the south, shoal development, point bar development, and switching of channels in central zones, and beach-ridge progradation to the north. The Frankland River Delta also is markedly asymmetrical in sedimentation style and in development of deltaic landforms, with beach-ridge progradation on its wave-exposed northern side, shoaling, channel switching, and digitate delta development in its central zone, and delta plain and platform development on its southern side.

The Walpole–Nornalup Inlet Estuary has a well-developed and pristine tidal delta (Figure 8.35). While it is a paired system with a large fan-shaped flood-tidal delta, and a smaller lobate ebb-tidal delta, overall, deposition is dominated by flooding tides. To provide access for fishing boats and to manage flooding, many tidal deltas in Western Australia have been modified to some extent or are maintained in a open-channel state by dredging (e.g., that in the Peel-Harvey Estuary is maintained by dredging; that in Wilson Inlet was dredged in the past; Hodgkin & Clark 1988a, 1988b; Semeniuk C A & Semeniuk 1990).

In Western Australia, the unique combination of humid climate has developed wetlands along the estuary shore. This refers not to the estuarine peripheral vegetation developed in the tidal zone and flood zone of the estuarine shore, but to the slopes bordering the estuary. Here, a unique series of wetlands are developed in the Walpole–Nornalup Inlet Estuary. The wetlands are palus slopes and slope mires (C A Semeniuk & Semeniuk 2011b) which are underlain by mud, muddy sand, peat, and peaty sand (Semeniuk et al. 2011). The cross-section shown in Figure 8.29, for instance, illustrates a peat-floored wetlands bordering the estuary shore.
There is an interesting lake within the Circus Beach Barrier in the Walpole-Nornalup Inlet Estuary system. In the global literature, it is considered to be a slack or a dune lake (Bayly & Williams 1973; Timms 1982; De Raeve 1987; Leentvaar 1997; Grootjans et al. 1998; Semeniuk & Semeniuk 2011a), i.e., a wetland formed by the wind excavation of a parabolic dune bowl. Most of the parabolic dunes in the barriers fronting the estuaries of the southern Western Australian coast are high-relief forms with little opportunity for parabolic bowls to be excavated to the water table (e.g., the Bellanger Barrier). In this context, regionally, the Lake is a unique and unusual wetland in this region and, further, provides a significant opportunity for stratigraphy and palynological studies.

The Holocene stratigraphy in the Walpole–Nornalup Inlet Estuary shows that mean sea level was 1 m higher than present some 2900-1200 years BP (Semeniuk et al. 2011; and Figure 8.36). There is a dearth of sea-level history data in this region, and the sea-level history of the Walpole–Nornalup Inlet Estuary may be distinct for this region and not represented in the other estuaries (that may have their own relative sea-level history).

There are ten stratigraphic formations defined in the Walpole–Nornalup Inlet area and their type sections provide a yardstick for what constitutes a formally defined formation (Semeniuk et al. 2011). They are invaluable sites for future researchers to visit, research, teach, and compare lithologically with other sections and profiles.

In addition to the sites of geoheritage significance described above, and somewhat overlapping in part with the sites described above, there are some sites of special interest in the Walpole–Nornalup Inlet area. These are: peat capping the deltaic sequences in all three deltas; peat along the estuarine shores, particularly along the eastern shore of Walpole Inlet; peat formed in response to subartesian upwelling as manifest along the north shore of the Coalmine Beach Peninsula; the occurrence of in situ polychaete and mollusc assemblages stranded 1 m above their current depositional environment; saprolitic gneiss in the cliffs near The Depot, weathered and softened in situ by salt water during a high sea-level stand (the profile shows relict gneissic layering and bioturbation of sand into the softened saprolite); palaeosols within the Conspicuous Cliff Sand (Semeniuk et al. 2011); and palaeosols within the Nornalup Sand.

In total, there are 23 geological features that characterise the "geoheritage essentials" of the Walpole–Nornalup Inlet Estuary; these are:

1. Precambrian rock sequences and landforms
2. gneissic control of estuarine form (morphology of the estuary)
3. twin-basin ria estuary
4. the Coalmine Beach Peninsula
5. the Coalmine Beach stratigraphy
6. Tertiary sediment sequences
7. Frankland River to barrier landform relationships
8. Quaternary stratigraphic sequences
9. Quaternary landforms
10. open coastal dune zone landforms
11. estuary shore landforms
12. complex & unique stratigraphy of the estuary shores
13. complex stratigraphy of the barrier dunes
14. stratigraphy and hydrology of the estuary shores
15. intra-estuarine deltas
16. asymmetric, heterogeneous, and polygenetic
17. nature of the intra-estuarine deltas
18. the tidal delta
19. wetlands along the estuary margin
20. lake within the Circus Beach Barrier
21. mean sea level history
22. stratigraphic type sections
23. isolated features of special interest
These features are described in terms of scale, geoheritage category, level of significance, and rationale for determining level of significance in Table 8.4.

In the region of the Walpole-Nornalup Inlet Estuary, there are only other three estuaries residing in the Albany-Fraser Orogen along the southern coast of Western Australia (Semeniuk et al. 2011), viz., Broke Inlet, Irwin Inlet, and Wilson Inlet. They have barriers but have different geometry and shoreline types. To place the Walpole-Nornalup Inlet Estuary into regional perspective, the estuary is compared in terms of physical, geometric, shoreline, and barrier attributes to the other three estuaries (Figure 8.37).

A summary of the geoheritage features of the Walpole-Nornalup Inlet Estuary, showing the categories of geoheritage sites in the area, a representative range of geological features at decreasing scale, and the assessment of significance of each of the geological essentials of the area are presented in Table 8.38.

The location of sites of significance and the proposed use of the area as a Geopark will be dealt with in the Chapter on Policy.
<table>
<thead>
<tr>
<th>Geological feature</th>
<th>Type of site, and its scale (category of site, Fig. 1)</th>
<th>Significance</th>
<th>Rationale for assigning the level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extent that a ria coast is developed</td>
<td>modern landscapes and setting (active processes) and potentially a megascale reference site; regional scale</td>
<td>International</td>
<td>the ria coast of the Kimberley region is globally an outstanding system in terms of its size and extent, its style of development, and its variability of geomorphic, stratigraphic, hydrological, hydrochemical, and diagenetic features</td>
</tr>
<tr>
<td>Types of rias developed as related to geology</td>
<td>modern landscapes and setting (active processes) and potentially a reference site; medium scale to large scale</td>
<td>International</td>
<td>in the literature, two classic ria forms have been assigned type locations in disparate areas (viz., transverse rias in the Adriatic Sea and south-western Ireland, and the marine inundated river valleys in north-western Spain); however, in the Kimberley region, both of these ria forms occur adjoin each other, and further occur within the same general oceanographic setting, with similar coastal processes, within a generally similar tropical climate, and a within a generally similar geology; this then is a feature of International significance and, ideally, the Kimberley Coast, comprising coastal forms developed on the Kimberley Basin and King Leopold Orogen should be viewed as the global type location for ria shores</td>
</tr>
<tr>
<td>Types of rias developed at different scales</td>
<td>modern landscapes and setting (active processes) and potentially reference sites; medium scale to regional scale</td>
<td>International</td>
<td>the Kimberley Coast presents a range of ria coast sizes and shapes, some that are fracture-and-fault controlled, varying from large gulls to small embayments to small ravines, with orientations that reflect the conjugate fault-and-fracture patterns of the region that resulted from the weathering/erosion of the sandstone bedrock, and some that are inundated, rounded hills and undulating terrain that resulted from the weathering/erosion of basaltic bedrock; with its expression of marine-inundated rivers, creeks, valley tracts, and ravines of various sizes as ria coasts (since all these marine-inundated valley forms are naturally inter-gradational and form an integrated network), the Kimberley Coast provides a standard of the range of shorelines in terms of shape, sizes, and coastal orientation, that can be assigned to ria coasts and, again, can be viewed as a global classroom or global reference site</td>
</tr>
<tr>
<td>Precambrian geology: geology, stratigraphy, transition of basin to orogen</td>
<td>geohistorical site; small scale to medium scale</td>
<td>International</td>
<td>the Kimberley Coast presents well-exposed and extensive coastal cliff outcrops of Precambrian geology, that for over 700 km of general coastal length, and ~ 4000 km of more detailed measured coastal length, exhibit along the shore the sedimentary rocks and facies changes within the Kimberley Basin, volcanic rocks of the Kimberley Basin, as well as the structures and lithology of the King Leopold Orogen, and the geological transition from rocks of the mobile zone (King Leopold Orogen) to those of the Kimberley Basin</td>
</tr>
<tr>
<td>Geomorphology expressed at coast</td>
<td>modern landscapes and setting (active processes) and potentially reference sites; medium scale to large scale</td>
<td>Depending on location, International to National to State/Regional</td>
<td>Globally unique assemblage of landscapes developed at the coast partly due to the processes of coastal erosion and partly due to inundation of ancestral landforms in a tropical macrotidal setting; the geology of the region is globally unique and, as such, the coastal geomorphology is also therefore fronting the sea, bordering the gulfs, framing the narrow inlets, or forming local islands, there are sandstone cliffs, cliffs with boulder and scree aprons, plunging basaltic cliffs, bluffs, other types of steep shores, coastally-located mesas, fretted coasts, two-layered and terraced islands and cliffs, and lithologically determined platforms; some of the key geomorphic features along the Kimberley Coast illustrate examples of coastal forms that are particular to the Kimberley region; described in detail in Brocx &amp; Semeniuk (2011b)</td>
</tr>
<tr>
<td>Biogenic coasts (algal and coral reefs)</td>
<td>modern landscapes and setting (active processes); small scale to large scale</td>
<td>International</td>
<td>algal reefs of the Kimberley Coast stand distinct as being a fringing algal reef type that inhabits sandstone and basalt rocky shores, forming shore parallel platforms/wedges, and further, these algal reefs are a phylogenetically complex biocoenosis of algae and encrusting and lithophagic invertebrate fauna, rather than an accreted aggregation of crustose algae</td>
</tr>
<tr>
<td>Tempestites</td>
<td>modern landscapes and setting (active processes) and geohistorical site; small scale to medium scale</td>
<td>International</td>
<td>the various types of tempestites in the region, features of mesoscale to microscale size, and assigned to the geoheritage category of modern landscapes and setting (active processes), are of International significance as modern sedimentary models of tropical zone deposits formed in a cyclone-influenced macrotidal coast where corals, shell gravel, reworked beach rock slabs, and local rocky shore derivatives form the source material</td>
</tr>
<tr>
<td>Barrier sand/gravel deposits</td>
<td>modern landscapes and setting (active processes); small scale to medium scale</td>
<td>International</td>
<td>gravel barriers (and gravelly shores) occur throughout the globe but are associated most commonly with formerly glaciated regions, tectonic coasts where streams deliver gravel to the shore, and wave-dominated rocky shores (Carter 1988; Carter &amp; Orford 1993), e.g., Chesil Bank barring The Fleet (Carr &amp; Blackley 1973), and Hazelmere Barrier, both in England; however, the gravel barriers of the Kimberley Coast are specifically formed across narrow ravines cut into Precambrian rock in a tropical macrotidal setting or are reworked scree deposits (where they front the coast) and, as such, are globally uncommon and Internationally significant</td>
</tr>
<tr>
<td>Bar-and-lagoon deposits</td>
<td>modern landscapes and setting (active processes); small scale to medium scale</td>
<td>International</td>
<td>bar-and-lagoon deposits, especially where the barriers are formed across narrow ravines, are globally uncommon; along the Kimberley Coast, the development of bar-and-lagoon systems in a setting of a tropical climate, macrotidal regime, and cyclone influence coast, barriers formed across narrow ravines and embayments cut into Precambrian rock are Internationally significant</td>
</tr>
<tr>
<td>Sedimentary sequences</td>
<td>modern landscapes and setting (active processes) and geohistorical site; small scale to large scale</td>
<td>International</td>
<td>the ensemble of sedimentary sequences along the Kimberley Coast, located in gulfs, tide-dominated deltas, rias, and other sedimentary settings, range from cyclone-generated tempestites, to mud-dominated systems; their associated stratigraphic packages, developed by macrotidal and tropical conditions represent a global classroom or global reference site that shows inter-relationship of morphology, and oceanographic factors such as tide-dominated or wave-dominated prevailing conditions, or cyclone generated conditions, sediment delivery, the dominance of gravel versus sand versus mud and, as such, are Internationally significant</td>
</tr>
<tr>
<td>Freshwater seepage and waterfalls</td>
<td>modern landscapes and setting (active processes); medium scale</td>
<td>International</td>
<td>freshwater seepages discharging into the high-tidal coastal zone, into scree developed along the interface between basalt and sandstone, and as waterfalls are widespread throughout the Kimberley Coast; fractured bedrock of the inland Precambrian system functions as a major freshwater aquifer which discharges freshwater into the high-tidal environment, influencing diagenetic and ecological processes (the latter, specifically for mangroves); such discharges are along the upper edge of a salt flat at its contact with rocky cliffs, but locally they appear within the salt flat; for mangrove systems (Semeniuk 1983, 1985), in a tropical ria coastal setting, this style and extent of freshwater seepage is a rare hydrological feature and is Internationally significant as a global classroom or global reference site; freshwater discharging into scree along the interface between basalt and sandstone are Nationally significant features and freshwater discharging from rivers, creeks, and rivulets, as waterfalls directly into the sea are Nationally significant features</td>
</tr>
<tr>
<td>Key hydrodynamic features</td>
<td>modern landscapes and setting (active processes); medium scale</td>
<td>International</td>
<td>the Kimberley Coast exhibits some key hydrodynamic aspects, such as the “horizontal waterfalls”; the “horizontal waterfalls” is a local area (Talbot Bay) within the ria complex of narrow inlets, parallel inlets, and serial narrow gaps cut into rocky ridges, developed on the King Leopold Orogen, in a macrotidal regime, where there is a lag of tidal water interchange between two parallel inlets and the open ocean developing water level differences of several metres across the gaps; this is an extraordinary tidal hydrodynamic feature because of the configuration of the ria shores and inlets, and is Internationally significant</td>
</tr>
<tr>
<td>Types of cliffs along rias and rocky shore geomorphology</td>
<td>modern landscapes and setting (active processes) and potentially reference site; medium scale to large scale</td>
<td>National</td>
<td>there are a variety of cliff types developed along the ria coast and rocky shores, the coastal geomorphology reflecting oceanographic processes, rock type, stratigraphic sequence, geological structure (viz., structural attitude), and the induration, weathered nature and coherence of the bedrock; range of rocky shores in this region results from the fact that the Kimberley Coast is so laterally extensive, and there is opportunity for a variety of Precambrian rock (of varying lithology and structural attitudes) to be</td>
</tr>
</tbody>
</table>
Processes of cliff erosion | modern landscapes and setting (active processes) and potentially reference site; medium scale | National | the erosional style of cliff development is specific to this region because of the tropical and macrotidal environment, wave action, the specific range of lithologies, structures of the lithologies (such as fractures and jointing), and the structural attitude of the rocks; variably along the coast there are extensive tracts (outcrops) of sandstone, or sandstone and siltstone, or basalt, or basalt with sandstone and these, exposed at the shore, are actively being eroded (depending on lithology) by mass wasting, undercutting of cliff faces, joint-block erosion, salt weathering, wave erosion, tidal current erosion, and bioerosion; the suite of processes-and-products is a Nationally significant classroom for erosion processes and erosional products

Salt weathering | modern landscapes and setting (active processes); fine scale to medium scale | National | salt weathering resulting in high-tidal pavements at about HAT (especially along the contact of the salt flats and bedrock cliffs) occurs on a variety of appropriately exposed rock types (e.g., basalt, dolerite, laterite, sandstone, and steeply dipping rocks); in the Kimberley region, these high-tidal pavements, indicative of macrotidal environments are coastal geomorphic features of National geoheritage significance

Types of coasts | modern landscapes and setting (active processes) and potentially reference site; medium scale to large scale | National | There are a variety of coastal types developed in the Kimberley region, viz., Types 1, 2, 5, 6, 7, 8, 9 and 12, detailed in Chapter 6 and, as an ensemble of coast types in the region, they comprise a Nationally significant classroom for coastal development and classification, particularly for those that are intergradational

Diagenetic coasts | modern landscapes and setting (active processes); fine scale to medium scale | National | diagenetic coastal types, specifically beach-rock armoured coasts or beach rock cemented ramps, though also occurring along the Canning Coast and Pilbara Coast (Semeniuk 1996; 2008), are not common throughout coastal mainland Australia and, as such, these coastal types along the Kimberley Coast are Nationally significant

Key coastal outcrops | modern landscapes and setting (active processes) and geohistorical sites; small scale to large scale | Depending on location, International to National to State/Regional | the prominent coastal outcrops along the Kimberley Coast include excellent exposures of sedimentary and volcanic rocks of the Kimberley Basin, and the rocks of the King Leopold Orogen and are unique to Australia; depending on location, extent of outcrop, and type of lithology (as described in the text above) they are of National to State-wide significance

Scenic vistas | modern landscapes and setting (active processes); large scale to medium scale | Depending on location, International to National to State/Regional | the Kimberley Coast with its scenic vistas of cliffs of various rock types, its coastal waterfalls, and coastal views, and its wilderness appeal is an attractive area for tourists and, depending on location, these vistas are of International to National to State-wide importance.
<table>
<thead>
<tr>
<th>Geological feature</th>
<th>Type of site, and its scale (category of site, Fig. 1)</th>
<th>Significance</th>
<th>Rationale for assigning the level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>tide-dominated delta of the Fitzroy River</td>
<td>modern landscapes and setting (active processes); regional scale</td>
<td>International</td>
<td>geomorphic, sedimentologic and stratigraphic description of a tide-dominated delta in a tropical semiarid climate; this is a tide-dominated delta globally with the largest tide</td>
</tr>
<tr>
<td>principles and processes of tidal erosion</td>
<td>modern landscapes and setting (active processes); fine scale to large scale</td>
<td>International</td>
<td>tidal creek erosion and formation of tidal landscapes provides an international model of coastal development in a tropical, macrotidal environment, particularly in the transition of the small scale to the large scale which provides a powerful natural laboratory</td>
</tr>
<tr>
<td>mangroves in response to coastal development</td>
<td>modern landscapes and setting (active processes); fine scale to large scale</td>
<td>International</td>
<td>an example of geodiversity where landscape evolution determines mangrove response</td>
</tr>
<tr>
<td>carbonate nodules</td>
<td>modern landscapes and setting (active processes); small scale</td>
<td>International</td>
<td>first description of the variety of Holocene carbonate nodules under tropical tidal flats; sets a standard as a type location for Holocene carbonate nodules under tidal flats</td>
</tr>
<tr>
<td>Holocene stratigraphy</td>
<td>geohistorical site; medium scale to large scale</td>
<td>International</td>
<td>one of the most stratigraphically complex tidal flat systems in the world and also unique because of its tropical and macrotidal setting; well exposed along Airport Creek</td>
</tr>
<tr>
<td>Pleistocene linear dunes and Holocene tidal flat sediment</td>
<td>geohistorical site; medium scale</td>
<td>International</td>
<td>significant site for stratigraphic relationship of Quaternary tidal sediments and linear desert dunes, for models of coastal geomorphic adjustments with sea level rise, and climatic history</td>
</tr>
<tr>
<td>Holocene stratigraphy at Christine Point</td>
<td>geohistorical site; medium scale to large scale</td>
<td>National</td>
<td>most southern deposits of “Big Swamp” phase of early Holocene sedimentation in northern Australia and important indicator of climate history and fossil mangrove biogeography</td>
</tr>
<tr>
<td>Pleistocene stratigraphy</td>
<td>geohistorical site; medium scale to large scale</td>
<td>National</td>
<td>first and only description to date nationally of Pleistocene tidal flat stratigraphy; an important record of Pleistocene climate history, sedimentation, and diagenesis</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Holocene mangrove stumps</th>
<th>geohistorical site; small scale to medium scale</th>
<th>National</th>
<th>outcrop of fossil mangrove stumps embedded <em>in situ</em> in grey clay, extending to below MSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>spits and cheniers</td>
<td>geohistorical site and modern landscapes and setting (active processes); medium scale to large scale</td>
<td>National</td>
<td>response of linear dunes to coastal erosion and the effect of coastal process on the exposed northern tip of Point Torment Peninsula; in Australia, this is the only sand-based north-facing peninsula in a large gulf, where wave cation, storms, and cyclones have reworked the sand peninsula to form a set of prograded parallel cheniers</td>
</tr>
<tr>
<td>freshwater seepage</td>
<td>modern landscapes and setting (active processes); medium scale</td>
<td>National</td>
<td>example of freshwater seepage from dune sand aquifer that has been onlapped by tidal flat sediments; this is only one of two places in Australia where tidal flat sediments onlap linear dunes, the latter discharging freshwater into the saline subsurface (Mathews et al. 2011; Semeniuk 1980, 1983, 2008)</td>
</tr>
<tr>
<td>stratigraphic type sections</td>
<td>reference sites; medium scale</td>
<td>State-wide/Regional</td>
<td>the area contains a number of stratigraphic type sections that are references section in the State or Nation for the relevant stratigraphic unit</td>
</tr>
</tbody>
</table>
Table 8.3. Features of geoheritage significance in Leschenault Peninsula and its leeward lagoon, and the rationale for the assessment

<table>
<thead>
<tr>
<th>Geological feature</th>
<th>Type of site, and its scale (category of site, Fig. 1)</th>
<th>Significance</th>
<th>Rationale for assigning the level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>calcrite in zone of capillary rise</td>
<td>modern landscapes and setting (active processes); small to fine scale feature</td>
<td>International</td>
<td>first and only description to date globally of Holocene calcrite forming in the zone of capillary rise in relationship to plants</td>
</tr>
<tr>
<td>calcrite at high/low stratigraphic levels;</td>
<td>geohistorical site; small to fine scale feature</td>
<td>International</td>
<td>first use of Holocene calcrite to reconstruct Holocene climate history</td>
</tr>
<tr>
<td>calcrite breccia floatstone</td>
<td>modern landscapes and setting (active processes); small to fine scale feature</td>
<td>International</td>
<td>first description of lenses of Holocene calcrite breccia floatstone in soils, developed as a consequence of tree heave by storms</td>
</tr>
<tr>
<td>complex stratigraphy of barrier</td>
<td>geohistorical site; medium scale feature</td>
<td>International</td>
<td>one of the most complex dune barriers stratigraphically in the world because of the local sea level history superimposed on dune barrier development</td>
</tr>
<tr>
<td>stranded submerged beach rock forming bands/ridges</td>
<td>modern landscapes and setting (active processes), and geohistorical site; medium to small scale feature</td>
<td>International</td>
<td>first and only description to date globally of stranded beach rock forming submerged shore-parallel bands/ridges with barrier retreat</td>
</tr>
<tr>
<td>biodiversity of foraminifera forming rich (neo)palaeontological assemblage</td>
<td>modern landscapes and setting; very fine scale feature</td>
<td>International</td>
<td>richest biodiversity of Holocene estuarine foraminifera (neo)palaeontologically in the world</td>
</tr>
<tr>
<td>linear retrograding barrier</td>
<td>modern landscapes and setting (active processes); large to medium scale feature</td>
<td>National</td>
<td>the only linear retrograding Holocene dune barrier barring a barrier-parallel linear lagoon in Western Australia, and only one of a few nationally; in terms of sediments, ecology, and hydrology of Leschenault Inlet and the dune barrier are incomparable to any other system in Australia</td>
</tr>
<tr>
<td>Holocene sea level history recorded in the stratigraphy</td>
<td>geohistorical site; small scale feature</td>
<td>National</td>
<td>Unique Holocene sea level history recorded in the stratigraphy and reflecting local tectonism</td>
</tr>
<tr>
<td>complex shorelines/stratigraphy along the dune/estuary interface</td>
<td>modern landscapes and setting (active processes); large to medium scale feature</td>
<td>National</td>
<td>since the dune barrier is only one of a few occurring Nationally, the complex of shorelines and stratigraphy at the dune/estuary interface in this climate setting are Nationally uncommon</td>
</tr>
<tr>
<td>Feature Description</td>
<td>Scale</td>
<td>Significance</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------------</td>
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<td>------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Calcite encrustation of sea rush roots</td>
<td>National</td>
<td>Encrustation (and permineralisation) by calcite. Mg-calcite, and dolomite</td>
<td></td>
</tr>
<tr>
<td>well-documented Holocene palynological record as a model for estuaries</td>
<td>National</td>
<td>The documented patterns of pollen distribution in the Holocene estuarine</td>
<td></td>
</tr>
<tr>
<td>Active parabolic dunes in barrier</td>
<td>State-wide/Regional</td>
<td>The geometry and style of active parabolic dune development within the</td>
<td></td>
</tr>
<tr>
<td>Gradational range of landscapes: mobile dune to undulating plain</td>
<td>State-wide/Regional</td>
<td>In this climate, with the vegetation contributing organic matter to soils,</td>
<td></td>
</tr>
<tr>
<td>Calcrite exposed in deflation bowls of parabolic dunes</td>
<td>State-wide/Regional</td>
<td>Normally, dune bowl excavation proceeds to the water table and forms</td>
<td></td>
</tr>
<tr>
<td>Beach rock in the tidal zone</td>
<td>State-wide/Regional</td>
<td>This type of beach rock is restricted to this part of Western Australia, and</td>
<td></td>
</tr>
<tr>
<td>Freshwater seepage at dune/estuary interface</td>
<td>State-wide/Regional</td>
<td>Freshwater seepage along the dune/estuary interface produces complex</td>
<td></td>
</tr>
<tr>
<td>Mangrove stand and its lithotope at dune/estuary interface</td>
<td>State-wide/Regional</td>
<td>A prominent mangrove stand is formed at the dune/estuary interface</td>
<td></td>
</tr>
<tr>
<td>Estuary western shore landforms graded south to north</td>
<td>State-wide/Regional</td>
<td>The south to north transition of shore landforms along the western estuary</td>
<td></td>
</tr>
</tbody>
</table>

**Table Notes:**
- **Scale:** State-wide/Regional, National, or State-wide/Regional
- **Significance:** The significance level ranges from local to national.
<table>
<thead>
<tr>
<th>north-south and east-west patterns in sediments and stratigraphy of estuary</th>
<th>modern landscapes and setting; large to medium scale feature</th>
<th>State-wide/Regional</th>
<th>the linear lagoon bordered by distinct landforms and provenances has resulted north-south and east-west patterns in sediments and stratigraphy of the estuary that are unique in Western Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>an intra-estuarine delta</td>
<td>modern landscapes and setting (active processes); medium scale feature</td>
<td>State-wide/Regional</td>
<td>at the southern end of a north-south oriented estuarine lagoon, the Collie Delta is asymmetric reflecting fluvial construction and a storm influenced northern part that faces the long fetch of the lagoon - a feature unique in Western Australia</td>
</tr>
<tr>
<td>peripheral wetlands along western and eastern shore of estuary;</td>
<td>modern landscapes and setting (active processes); large scale feature</td>
<td>State-wide/Regional</td>
<td>the stratigraphy, landforms, and freshwater seepage along the estuarine shores from the dune barrier and the Eaton Ridge has resulted in distinct peripheral wetlands along western and eastern shores of the estuary that are found nowhere else in Western Australia</td>
</tr>
<tr>
<td>stratigraphic type sections; reference sites; small scale feature</td>
<td>State-wide/Regional</td>
<td>the area contains a number of stratigraphic type sections</td>
<td></td>
</tr>
<tr>
<td>Geological feature</td>
<td>Type of site, and its scale (category of site, Fig. 1)</td>
<td>Significance</td>
<td>Rationale for assigning the level of significance</td>
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<tr>
<td>--------------------------------------------------------</td>
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</tr>
<tr>
<td>Precambrian rock sequences and landforms</td>
<td>geohistorical, and modern landscapes and setting (active processes); large scale feature</td>
<td>Regional</td>
<td>variety of metamorphic and igneous rock types distinct to this part of the Albany-Fraser Orogen of southern Western Australia (Wilde &amp; Walker 1984; Semeniuk et al. 2011)</td>
</tr>
<tr>
<td>gneissic control of estuarine form (morphology of the estuary)</td>
<td>modern landscapes and setting (active processes); large scale feature</td>
<td>State-wide</td>
<td>the geological strike of the mega lithologic units control the shape of the estuary, the only such example in coastal Western Australia</td>
</tr>
<tr>
<td>Coalmine Beach stratigraphy</td>
<td>geohistorical site; medium scale feature</td>
<td>Regional</td>
<td>Coalmine Beach Peninsula shows excellent exposures of Tertiary stratigraphy, which are unusual in southern Western Australia (see Wilde &amp; Walker 1984; Geological Survey of WA 1990; Semeniuk et al. 2011); the exposure is well preserved because the rocks are protected from Southern Ocean swell by the estuarine setting</td>
</tr>
<tr>
<td>Tertiary sediment sequences</td>
<td>geohistorical site; small scale feature</td>
<td>Regional to State-wide</td>
<td>the stratigraphy along the Coalmine Beach Peninsula is well exposed, and provides good examples of the Tertiary sequences, unlike in other coastal locations that are more exposed to Southern Ocean swell</td>
</tr>
<tr>
<td>Frankland River to barrier landform relationships</td>
<td>modern landscapes and setting (active processes); large scale feature</td>
<td>State-wide</td>
<td>the Bellanger Barrier has in a major way deflected the major river of the Frankland, producing river to barrier landform relationships that is unique in Western Australia</td>
</tr>
<tr>
<td>Quaternary stratigraphic sequences</td>
<td>geohistorical site; medium scale to small scale feature</td>
<td>Regional to State-wide</td>
<td>the barrier, estuary and hinterland has produced a complex array of stratigraphic sequences that are well developed and unique to estuary/barrier situations in Western Australia</td>
</tr>
<tr>
<td>Quaternary landforms</td>
<td>modern landscapes and setting (active processes); medium scale feature</td>
<td>Regional</td>
<td>the barrier, estuary and hinterland in this Southern Ocean setting have produced a complex array of Quaternary landforms that are well developed and unique to estuary/barrier situations in Western Australia</td>
</tr>
<tr>
<td>open coastal dune zone landforms</td>
<td>modern landscapes and setting (active processes); large scale feature</td>
<td>State-wide</td>
<td>the barrier, barring the estuary, and facing the Southern Ocean setting has produced open coastal dune landforms that are well developed and unique to estuary/barrier situations in Western Australia</td>
</tr>
<tr>
<td>estuary shore landforms</td>
<td>modern landscapes and setting (active processes); large scale feature</td>
<td>State-wide</td>
<td>the estuary, because of its shape and its relationship to the barrier has produced estuary shore landforms that are well developed and unique to estuaries in Western Australia</td>
</tr>
<tr>
<td>Feature Description</td>
<td>Geohistorical Sites</td>
<td>Reference Sites</td>
<td>Scale</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>complex and unique stratigraphy of the estuary shores</td>
<td>geohistorical sites; reference sites; medium scale to small scale feature</td>
<td>State-wide</td>
<td>because of its geological setting and Quaternary history, the area contains a distinctive stratigraphy along the estuarine shores unique to estuaries in Western Australia</td>
</tr>
<tr>
<td>complex stratigraphy of the barrier dunes</td>
<td>geohistorical sites; reference sites; large scale feature</td>
<td>Regional</td>
<td>because of its coastal and oceanographic setting, the barrier is complex in its history, and contains a number of distinctive stratigraphic type sections unique to estuaries in Western Australia</td>
</tr>
<tr>
<td>stratigraphy and hydrology of the estuary shores</td>
<td>geohistorical sites and modern landscapes and setting (active processes); reference sites; large to small scale feature</td>
<td>State-wide</td>
<td>the stratigraphy and hydrology of the estuarine shore are closely inter-related, and the varied and complex stratigraphy of the estuarine shores has resulted in a varied and complex coastal hydrology unique to estuarine Western Australia</td>
</tr>
<tr>
<td>intra-estuarine deltas</td>
<td>geohistorical sites and modern landscapes and setting (active processes); reference sites; large scale feature</td>
<td>National</td>
<td>three rivers drain into the estuary creating intra-estuarine deltas that are distinct to Western Australia; the deltas in different hydrodynamic settings; the deltas are variably exposed to wave actions, or tides or are dominated by fluvial processes and this has resulted in variable delta forms that are dependent on the estuarine setting of a given delta</td>
</tr>
<tr>
<td>asymmetric, heterogeneous, and polygenetic nature of the intra-estuarine deltas</td>
<td>geohistorical sites and modern landscapes and setting (active processes); reference sites; large scale feature</td>
<td>International</td>
<td>each of the three deltas in their different hydrodynamic settings have produced distinctively different forms in terms of their asymmetry, heterogeneity, and polygenetic nature; the deltas reflect their asymmetric formation depending on whether their components are wave-dominated, tide-dominated, or fluvially dominated</td>
</tr>
<tr>
<td>the tidal delta</td>
<td>modern landscapes and setting (active processes); reference sites; medium scale feature</td>
<td>State-wide</td>
<td>the entrance inlet of the estuary has produced a large and distinctive flood-tidal delta unique in form and size in Western Australia</td>
</tr>
<tr>
<td>wetlands along the estuary margin</td>
<td>modern landscapes and setting (active processes); reference sites; Medium scale feature</td>
<td>National</td>
<td>in this most humid part of Western Australia, this estuarine system is bordered by wetlands (mainly paluslopes) that are variable in form and dynamics dependent on estuarine setting; in the humid climate, the wetlands are underlain by peat; the ensemble of wetlands bordering this estuary and their peat deposits are unique to this part of Western Australia</td>
</tr>
<tr>
<td>lake within the Circus Beach Barrier</td>
<td>modern landscapes and setting (active processes); reference sites; medium scale feature</td>
<td>State-wide</td>
<td>the dune lake in the Circus Beach Barrier, formed by wind deflation and water table rise, is a unique landform to coastal Western Australia</td>
</tr>
<tr>
<td>Mean sea level history</td>
<td>Geohistorical site; small scale feature</td>
<td>State-wide</td>
<td>There is a unique local Holocene sea level history recorded in the shallow marine deposits in this area that is different to the rest of coastal Western Australia</td>
</tr>
<tr>
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</tr>
<tr>
<td>Stratigraphic type sections</td>
<td>Geohistorical site; small scale feature</td>
<td>State-wide</td>
<td>The area contains a number of stratigraphic type sections</td>
</tr>
<tr>
<td>Features of special interest</td>
<td>Geohistorical site; small scale feature</td>
<td>Regional, to State-wide significance</td>
<td>There are a number of significant geological features of special interest in this estuarine area; these are: peat capping the deltaic sequences in all three deltas; peat formed in response to subartesian upwelling the occurrence of <em>in situ</em> polychaete and mollusc assemblages stranded 1 m above their current environment; saprolitic gneiss in the cliffs; and local palaeosols (see Semeniuk et al. 2011 for more details)</td>
</tr>
</tbody>
</table>
Table 8.5. Features of geoheritage significance at Willie Creek, Entrance Point, Point Leander, and Muderup Rocks, and the rationale for the assessment

<table>
<thead>
<tr>
<th>Geological location and feature</th>
<th>Type of site, and its scale (category of site, Fig. 1)</th>
<th>Significance</th>
<th>Rationale for assigning the level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willie Creek</td>
<td>geohistorical site; medium scale to regional scale</td>
<td>International</td>
<td>tropical macrotidal shoaling sandy sequences have not been described elsewhere in Australia nor globally and, as such, the Willie Creek site is a geological feature of global importance; it illustrates lithologies that are generated by progradation in tropical macrotidal sandy coastlines.</td>
</tr>
<tr>
<td>Holocene tidal flat sand,</td>
<td>geohistorical site; medium scale to regional scale</td>
<td>International</td>
<td>while oolitic sands are accumulating today in the marine wave-agitated shallow-water environments in the Bahama Banks, and Shark Bay, and are common in Pleistocene limestones, the oolitic sand grains and layers mid-Holocene deposits at Willie Creek are an unusual oolitic limestone in a worldwide context.</td>
</tr>
<tr>
<td>beach deposits, and dunes now</td>
<td>geohistorical site; medium scale to regional scale</td>
<td>International</td>
<td>while beach rock has been described from modern environments, generally it is not described from ancient deposit sequences; the in situ beach rock stands as a unique global stratigraphic example of such a lithology within the shoaling macrotidal system.</td>
</tr>
<tr>
<td>cemented to limestone</td>
<td>geohistorical site; small scale to medium scale</td>
<td>International</td>
<td>ancient signatures of cyclones, viz., deposits of cyclone-generated fragments of beach rock as breccia and conglomerate, as cyclone-generated cliffs cut into beach rock, and scour-and-fill in the beach sediments are not well described in the literature and, as such, the deposits in the Kennedy Cottage Limestone represent a unique global stratigraphic example of these lithologies within the macrotidal sandy coastal system.</td>
</tr>
<tr>
<td>oolite in the stratigraphic</td>
<td>geohistorical site; small scale to medium scale</td>
<td>International</td>
<td>the record of a mid-Holocene higher sea level adds to the Australian National patterns.</td>
</tr>
<tr>
<td>sequence</td>
<td>geohistorical site; small scale to medium scale</td>
<td>National</td>
<td>the Willie Creek area is the site for three stratigraphic type sections, viz., the Horsewater Soak Calcarenite, the Kennedys Cottage Limestone, and the Willie Creek Calcarenite.</td>
</tr>
<tr>
<td>the preservation of beach rock</td>
<td>geohistorical site; small scale to medium scale</td>
<td>National</td>
<td>the sequence of well-preserved siliciclastic tidal flat facies is a feature that has not been as well preserved in Mesozoic sedimentary rocks in Australia or globally; the Entrance Point locality presents excellent wave-washed and salt-weathered exposure of a wide variety of siliciclastic tidal flat sedimentary rocks that illustrate stratigraphic sequence, sedimentary structures, lithologies, and sedimentary micro-history – it stands a model of siliciclastic sedimentation on a tidal flat for the Mesozoic globally.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Geohistorical Site</th>
<th>Scale</th>
<th>Significance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point Leander</td>
<td></td>
<td>National</td>
<td>the limestone outcrop at Point Leander uniquely shows the internal structure of a coral reef not present elsewhere in the Western Australia, nor in Australia. It stands as a model of coral reef accretion for Western Australia and Australia. In this context, the site is of National Geoheritage significance.</td>
</tr>
<tr>
<td>Muderup Rocks</td>
<td></td>
<td>International</td>
<td>this Pleistocene rocky shore is an uncommon feature to be so well preserved; the outcrop presents an excellent wave-washed and salt-weathered exposure of a wide variety of rocky shore features that illustrate processes and products during Pleistocene rocky shore development in terms of sequence, sedimentary structures, lithologies, and biological effects – it stands a model of rocky shore development for the Pleistocene globally.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>International</td>
<td>Muderup Rocks presents an excellent wave-washed and salt-weathered exposure of an unconformity between a rocky shore and beach sediment, and a beach to dune stratigraphy that illustrates sequence, sedimentary structures, lithologies, and sedimentary processes and products – it stands a model of an unconformity between a rocky shore to beach sediment, and the beach to dune carbonate sedimentation for the Pleistocene.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Local</td>
<td>yellow sand unconformable on limestone, pipes penetrating the limestone, yellow sand infilling the pipes, calcrite linings and capping, and the calcreted rootlets while well-developed at Muderup Rocks are features quite ubiquitous along the coastal-exposed Pleistocene limestones of the Perth Basin; they are not well developed in the Bridgewater Formation elsewhere in Australia but relatively common when viewed globally; as such the features of yellow sand and calcrite and their inter-relationships is a feature at Muderup Rocks of Local Geoheritage significance.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>International</td>
<td>this rocky shore bench had been interpreted by Fairbridge (1950) as a former Holocene sea level indicator; the bench stands as an example of contrasting interpretations of a sea level indicator and illustrates the complex developmental history of the rocky shore and how Pleistocene sea level indicators can be incorrectly assigned to a former Holocene sea level history – this stands as an example to the international community; the rocky shore also has cultural significance; the local Indigenous peoples consider Muderup to be a spiritual site.</td>
</tr>
</tbody>
</table>
Application of the Geoheritage Tool-kit in Western Australia: case studies at the small scale

Four case studies at the small scale in Western Australia illustrate the use of the Geoheritage Tool-kit, wherein geological features at small-scale are identified and assessed as a basis for designating geosites; from north to south, the study areas are (Figure 8.1):

1. Holocene limestone stratigraphy at Willie Creek, northern Broome region,
2. Mesozoic Broome Sandstone stratigraphy at Entrance Point cliffs, Broome region,
3. Pleistocene coral reef limestone, Point Leander, Dongara region;
4. Pleistocene limestone rocky shore and beach/dune limestone sequence, Muderup Rocks, south Cottesloe, Perth region.

The geoheritage essentials of the various geosites are described below. This is followed by a description and assessment of the key geological features identified in the geosites in terms of the type of site and its scale, category of feature (from Figures 2.6 & 7.1), significance of geological features, and rationale for assigning the level of significance. The results are presented in Table 8.5.

Though not listed as such in Table 8.5 (because the focus in Table 8.5 is on geology and its geoheritage significance), the local areas of Willie Creek Holocene limestone, Entrance Point cliffs, and Muderup Rocks are significant cultural site to the Indigenous peoples of the region. The importance of these sites to the Indigenous peoples lies not in the geological attributes such as stratigraphy, lithology, or geohistory, but in their spiritual beliefs, food gathering, and settlements.

1. Holocene limestone stratigraphy at Willie Creek

The Holocene limestone stratigraphy at Willie Creek, north of Broome (Figure 8.1) exposes a sequence, some 5500 years old, of macrotidal sandy shoaling sequence, now weakly lithified to limestone (Semeniuk 2008). The shoaling sequence, up to 10 m thick, consists of shelly sandy sediment that accumulated in low tidal flat environments, overlain by shelly sand and sand sediment that accumulated in beach to dune environments. The sequence is geohistorical and, as such, the present climate and oceanographic setting of the locality are not directly relevant. In terms of classification for comparative coastal geoheritage purposes, the Willie Creek area is assigned to the geological region of the Canning Coast as part of the Canning Basin, and in terms of coastal types, assigned to Coastal Type 11, a Holocene depositional coasts recording sedimentary history, ocean history, climate history and sea-level history, and Coastal Type 12, sea cliffs exposing lithology, stratigraphic sequences and contacts, and structure.

As an overview, Willie Creek is a palmate embayment coast cut into Quaternary red sand (Mowanjum Sand), with local beaches, beach ridges and dune barrier along the sea-front (Figure 8.39). Calcilutite fills the embayment, and middle Holocene sandy and shelly sediments (now limestone) were deposited with sea level 1.5-2.0 m above present, and form a barrier across the entrance to the embayment (Semeniuk 2008).

While the ensemble of calcilutite-filled embayment with the limestone barrier and modern deposits of beaches, beach ridges, and dunes is a coastal site of geoheritage significance along the Canning Coast, the focus for the geosite in this case study is specifically the Holocene limestone.
In total, there are 6 features that characterise the "geoheritage essentials" of the Holocene limestone in the Willie Creek area; these are:

1. Holocene tidal flat sand, beach deposits, and dunes now cemented to limestone
2. oolite in the stratigraphic sequence
3. the preservation of beach rock
4. the signature of cyclones and their deposits
5. mean sea level history
6. stratigraphic type sections

Table 8.5 summarises the geoheritage features of the Willie Creek Holocene limestones, showing the categories of geoheritage features in the area. These features are described in terms of scale, geoheritage category, level of significance of each of the geological essentials of the site, and rationale for determining the level of significance.

The first of the features of geoheritage significance in the Willie Creek area is the sequence of Holocene tidal flat sand, beach deposits, and dunes now cemented to limestone, and the lithology of the tidal zone facies. These Holocene limestones are exposed in the cliffs at the entrance of Willie Creek are comprised of three formations (Semeniuk 2008): These are described below in terms of their structures and lithology, and any key features.

1. a lower unit, defined by Semeniuk (2008) as the Willie Creek Calcarenite, which is a distinctive limestone unit formed earlier during the Holocene as a low tidal sand and shelly sand deposit with an abundant ichnofauna; it is 3-5 m thick, bedded to large-scale festoon-bedded, laminated, burrow-structured to bioturbated calcarenite and shelly calcarenite (Semeniuk 2008); as a sedimentary deposit, it formed as a mid- to low tidal sand and shelly sand during the mid-Holocene along the coastal zone of the Canning Coast – it is typical of low tidal sand flats;

2. a middle unit, defined by Semeniuk (2008) as the Kennedys Cottage Limestone, which is a laminated to cross-laminated calcarenite limestone also formed earlier during the Holocene as beach deposit; it is 1.5-2.0 m thick, and comprised of shelly calcarenite with limestone intraclast conglomerate and breccia, and with bubble sand structures; it has the sedimentary structures and interlayering of sediments typical of beaches; diagnostic features are bubble sand structure, in situ beach rock, and breccia/conglomerate of beach rock slabs; the limestone intraclast conglomerate and breccia are storm reworking of beach rock sheets; the sedimentary suite, with its indicative sea level markers, is located about 1.5 m to 2 m above the level of contemporary beach deposits.

3. an upper unit, defined by Semeniuk (2008) as the Horsewater Soak Calcarenite, which is a cross-laminated and cross-bedded sandy aeolian deposit (now limestone, or aeolianite); it is 2-3 m thick, and consists of fine to medium sand-sized bioclastic and quartzose, and locally oolitic calcarenite); it is generally a shore-parallel shoe-string deposit deposited as mid-Holocene supratidal coastal dunes, and later lithified.

The tropical macrotidal shoaling sandy sequence situated 1.5 to 2.0 m above present mean sea level, as described by Semeniuk (2008), is a feature that has not been recognised in Australia nor globally and, as such, is a geological feature of global importance. It illustrates the range of lithologies that are generated by progradation in tropical macrotidal sandy coastlines. In this context, the site is of International Geoheritage significance.
Locally in the aeolianite of the Horsewater Soak Calcarenite there are ooid grains and oolitic layers (Semeniuk 2008). These are unusual as grain types and lithologies in Western Australia and globally. Oolitic sands are accumulating today in the marine wave-agitated shallow-water bank-edge environments of upwelling currents in the Bahama Banks (Ball 1967; Bathurst 1975; Halley et al. 1983), in the wave-agitated shallow-water shoal environments in hypersaline basins of Shark Bay (Logan 1974). Those oolitic sand grains and oolite layers deposited in the mid-Holocene at Willie Creek are part of the belt of Horsewater Soak Calcarenite that is patchily distributed along the Canning Coast and, as an occurrence of unusual oolitic limestone in a worldwide context, the belt of Horsewater Soak Calcarenite and the well-exposed occurrence at Willie Creek are globally important. In this context, the site is of International Geoheritage significance.

The lithological and sedimentary-structural signatures of beaches have been described by Clifton (1969) and Semeniuk & Johnson (1982). They describe the range of small scale lithologies and sedimentary structures in a shoaling beach sequence but in microtidal environments. Macrotidal shoaling sandy coastal deposits are not so well described in the literature and, as such, the sequence at Willie Creek of the Willie Creek Calcarenite, Kennedy Cottage Limestone, and Horsewater Soak Calcarenite stands as a unique global stratigraphic example of shoaling macrotidal system set in a tropical climate. In this context, the site is of International Geoheritage significance.

Similarly, while beach rock has been described from modern environments, generally beach rock is not described from older sequences. Fossil beach rock occurs *in situ* in the beach facies of the Kennedy Cottage Limestone (Semeniuk 2008). It occurs as a calcarenite more strongly indurated than the enclosing calcarenite of the Kennedy Cottage Limestone. Again, beach rock as an ancient deposit is not so well described in the literature and, as such, the *in situ* beach rock in the Kennedy Cottage Limestone sequence at Willie Creek stands as a unique global stratigraphic example of such a lithology within the shoaling macrotidal system. In this context, the site is of International Geoheritage significance.

The cyclone-generated deposits are represented by breccia and conglomerate layers in the upper part of the beach facies of the Kennedy Cottage Limestone and lower part of the Horsewater Soak Calcarenite (Semeniuk 2008). The breccia and conglomerate are ripped-up slabs of beach rock that have been undermined and delivered shore-wards under conditions of cyclonic activity and elevated sea levels during such storms. Associated with the breccia and conglomerate layers are cliffs cut into the beach rock layers, and scour-and-fill in the beach sediments. These lithologic features are the diagnostic signature of cyclones. Ancient deposits of cyclone-generated fragments of beach rock as breccia and conglomerate, as cyclone-generated cliffs cut into beach rock, and scour-and-fill in the beach sediments are not well described in the literature and, as such, the signature of cyclones and their deposits in the Kennedy Cottage Limestone sequence at Willie Creek represents a record of mid-Holocene cyclone activity and stands as a unique global stratigraphic example of these lithologies within the macrotidal sandy coastal system. In this context, the site is of International Geoheritage significance.

The Holocene limestones at Willie Creek record a mid-Holocene sea level high-stand of 1.5-2.0 m above present mean sea level. Such higher sea level stands have been recorded around Australia and Western Australia by Logan (1970), Belperio (1995), Semeniuk & Searle (1985), Semeniuk (1985, 1995), and Semeniuk et al (2011). The record of a mid-Holocene higher sea level adds to the Australian national patterns and, as such, for this adds to the sea level history for this part of the continent. The stratigraphy recording the mid-Holocene sea level history is a site of National Geoheritage significance.
Finally, the Willie Creek area is the site for three stratigraphic type sections (Semeniuk 2008), viz., the Horsewater Soak Calcarenite, the Kennedys Cottage Limestone, and the Willie Creek Calcarenite. In this context, the site is of State Geoheritage significance.

2. Mesozoic stratigraphy of Broome Sandstone at Entrance Point

The Mesozoic Broome Sandstone is well exposed at Entrance Point, Broome (Figure 8.1) where it illustrates a range of stratigraphic, sedimentary-structural, and lithologic features (Brunnschweiller 1954; Brocx & Semeniuk 2010a). The stratigraphic sequence of the Broome Sandstone at Entrance Point is up to 10 m thick, consists of interlayered sandstone, siltstone, and claystone that accumulated in siliciclastic tidal flat environments. The sequence is geohistorical and, as such, the present climate and oceanographic setting of the locality are not relevant. In terms of classification for comparative coastal geoheritage purposes, the Mesozoic sandstone at Entrance Point is assigned to the geological region of the Canning Coast as part of the Canning Basin, and in terms of coastal types, assigned to Coastal Type 3 (landforms wholly developed by coastal erosion, or where erosion has totally or nearly totally overprinted primary (pre-transgression) hinterland landforms) and Coastal Type 12 (sea cliffs exposing lithology, stratigraphic sequences and contacts, and structure).

Entrance Point is a rocky headland cut into the Broome Sandstone (Figure 8.40) and into Quaternary red sand (Mowanjum Sand). The headland cut into the Broome Sandstone illustrates classic rock shore features of cliffs, stacks, benches, structural platforms, and notches, at the smaller scales, salt weathering (etched surfaces) and tafoni (cf. rocky shore refs). Locally there also is Holocene beach rock (Semeniuk 2008). These aspects of the geology of Entrance Point, while of some geoheritage importance, are not described/discussed further as the focus is on the cliffs cut into the Broome Sandstone that exposes Mesozoic lithologies and palaeo-environments.

The main geoheritage features of the stratigraphy and lithology of the Broome Sandstone at Entrance Point are its illustration of Mesozoic tidal flat facies.

Based on information on siliciclastic tidal flat facies in Thompson (1968), Reineck (1975), Ginsberg (1975), Reineck & Singh (1980), and Semeniuk (1981b, 2005), there are 12 key features of stratigraphy, lithology and sedimentary structures that indicate tidal flat conditions in the Broome Sandstone at Entrance Point are (Figures 8.41, 8.42, & 8.43):

1. large scale cross-bedding and festoon cross-bedding in sandstone (with cross-bedding sets up to 0.5 m high) that records migrating megaripples on a sandy tidal flat;
2. small-scale cross-bedding and festoon cross-bedding in sandstone (with cross-bedding sets up to 5 cm high) that records migrating ripples on a sandy tidal flat;
3. beds of sandstone showing structures of ripple drift and climbing ripples (sets up to 5 cm high) that records migrating ripples on a sandy tidal flat;
4. beds of sandstone showing ripple-cross-laminated sandstone, wavey lamination, and flazer structures of ripple-cross-laminated sandstone with thin lenses of mud in the inter-ripple troughs; these record ripples on a sandy tidal flat, migrating ripples on a sandy tidal flat, and migrating ripples on a sandy tidal flat with later settling of mud into the inter-ripple troughs;
5. beds of sandstone 3-5 cm thick, showing bubble sand structures that records a tidal flat water table rising into the sediment on a rising tide on a sandy tidal flat;
6. bedding plane exposures of sandstone showing variously oriented sets of low-relief ripples; these illustrate shallow water conditions wherein variable wind directions have generated wind waves and currents that have rippled the sandy floor;
7. Channel-form structures, 10 cm to 50 cm deep and up to 2 m wide, filled with cross-bedded sandstone, or with interlayered sandstone and mudstone, or filling with sandstone at the base grading to interlayered sandstone and mudstone; where there are interlayered lithologies, the layering initially conforms to the base of the channel floor and, with filling of the channel, progressively becomes parallel to the sedimentary surface; these channel-form structures record low-relief tidal drainage channels on a tidal flat that (once abandoned) have filled with sand or interlayered sand and mud;

8. Sheets of interlayered sandstone and mudstone that are laterally extensive for up to 10 m before being truncated by a low-angle erosional surface; these illustrate tidal flat sedimentation of alternating sand and mud (probably reflecting spring tide and neap tide sedimentation phases);

9. Sheets of interlayered sandstone and mudstone that are laterally extensive for up to 10 m that show vertical burrow structures that penetrate the sandstone and mudstone layers; these illustrate tidal flat sedimentation of alternating sand and mud (probably reflecting spring tide and neap tide sedimentation phases), but with biogenic burrowing activity;

10. Sheets of mudstone that are perforated by small millimetre-sized vertical burrows; these illustrate tidal flat sedimentation dominated by mud, and with biogenic burrowing activity;

11. Sheets of mudstone that are desiccated (with in situ cracks); these illustrate mud sheets that have been desiccated during low tide or during neap tide phases;

12. Sheets of flat mudstone clasts as mud flake chips (flat-pebble breccia and conglomerate), with clasts 1-2 mm in thickness and 2-5 cm across; these illustrate extreme desiccation of the mud sheets to generate mud curls and mud clasts, and reworking of the cracked mud to form the sheets of breccia and conglomerate.

This sequence of well-preserved tidal flat facies in the Broome Sandstone is a feature that has not been as well preserved in Mesozoic sedimentary rocks in Australia or globally. The literature review presented earlier shows that while there has been a focus on Mesozoic carbonate rocks of a tidal flat nature, there has not been a description of tidal flat facies in siliciclastic sequences in the Mesozoic. Also, where there have been descriptions of Mesozoic tidal flat facies in siliciclastic sequences, these generally have been from drill cores and not from laterally extensive wave-washed outcrops that show lateral and vertical relationships between lithologies. The Entrance Point locality presents excellent wave-washed and salt-weathered exposure of a wide variety of tidal flat siliciclastic sedimentary rocks that illustrate stratigraphic sequence, sedimentary structures, lithologies, and sedimentary microhistory – it stands as a model of siliciclastic sedimentation on a tidal flat for the Mesozoic globally. In this context, the site is of International Geoheritage significance.

3. Pleistocene coral reef, Point Leander, Dongara region

Point Leander, Dongara, has a cliff exposure of a Pleistocene coral reef (Figure 8.1) and illustrates a range of stratigraphic, sedimentary-structural, and lithologic features of coral reefs. The coral reef is up to 2 m thick and consists of various types of reefal limestone and a carbonate-skeletal calcirudite-and (gastropod-dominated) calcarenite-filled channel. The sequence is of geohistorical significance and thus the present climate and oceanographic setting of the locality are not relevant. In terms of classification for comparative coastal geoheritage purposes, the Pleistocene coral reef at Point Leander is assigned to the geological region of the Perth Basin and, in terms of coastal types, assigned to Coastal Type 3 (landforms wholly developed by coastal erosion, or where erosion has totally or nearly totally overprinted primary (pre-transgression) hinterland landforms) and Coastal Type 12 (sea cliffs exposing lithology, stratigraphic sequences and contacts, and structure).
Point Leander is a rocky shore cut into the Pleistocene limestone (of an unassigned formation). The headland illustrates classic limestone rock shore features of cliffs, stacks, benches, structural platforms, and notches, at the smaller scales, salt weathering, and micro-pinnacles (cf. Semeniuk & Johnson 1985). These aspects of the rocky shore geomorphology of Point Leander, while of some geoheritage importance, are not described/discussed further as the focus is on the cliffs that expose Pleistocene coral reef.

The main geoheritage features of the stratigraphy and lithology of the Pleistocene coral reef at Point Leander are its reef structure and lithologies. Based on information on coral reef facies in James & Ginsburg (1979), James (1983), Hopley (1982, 2011), Tucker & Wright (1990), Hopley et al. (2007), the key features of this Pleistocene coral reef are (Figures 8.44 & 8.45):

1. coral reef structure that internally illustrates a classic boundstone of coral forms interlocking to form a frame, cemented by crustose calcareous algae, and with an inter-frame fill of skeletal sand as derived from coral and other reef-dwelling invertebrate fauna skeletons; this indicates fringing coastal reef system rather than an offshore emergent coral reef system for this coastal region;
2. within the coral reef, there is a shoaling sequence of coral forms showing an upward sequence of coral plates overlain by coral fingers, or by coral heads, and then staghorn corals, that indicate vertical accretion of coral species from moderately deep water to shallow water;
3. crustose calcareous algae encircling the various corals in a binding function;
4. diverse fossil fauna and flora lodged as sand-sized and granule-sized grains between the frame of coral (viz., gastropods, bivalves crustaceans, bryozoans, fragments of crustose calcareous algae, fragments and segments of articulated calcareous algae); also an encrusting fossil fauna (viz., serpulid worms, byrozoans, bivalves); and
5. a channel filled with skeletal gravel and coarse sand is cut into the coral reef; the channel is some 1 m deep (thick) and > 5 m across.

This sequence of well-preserved Pleistocene coral reef facies at Point Leander is the best preserved example of a coral reef in the Perth Basin. There are Pleistocene coral reefs elsewhere in Western Australia, nor in Australia. It stands as a model of coral reef accretion for Western Australia and Australia. In this context, the site is of National Geoheritage significance.
4. Pleistocene limestone rocky shore and beach/dune sequence, Muderup Rocks

A complex stratigraphy of Pleistocene limestone is exposed at Muderup Rocks (Figure 8.1) illustrating an unconformity as a fossil rocky shore cut into limestone, a sequence of shoaling beach to dune calcarenites above the unconformity, desertic yellow sand unconformable on the beach to dune sequence, a range of stratigraphic, sedimentary-structural, and lithologic features, and diagenesis of rocky shores and subaerially exposed aeolianites. The stratigraphic sequence at Muderup Rocks is up to 6 m thick. The sequence is geohistorical and, as such, the present climate and oceanographic setting of the locality are not relevant. In terms of classification for comparative coastal geoheritage purposes, the Pleistocene limestone at Muderup Rocks is assigned to the geological region of the Perth Basin, and in terms of coastal types, assigned to Coastal Type 3 (landforms wholly developed by coastal erosion, or where erosion has totally or nearly totally overprinted primary (pre-transgression) hinterland landforms) and Coastal Type 12 (sea cliffs exposing lithology, stratigraphic sequences and contacts, and structure).

Muderup Rocks is a rocky headland cut into Pleistocene limestone and yellow sand. Most of the headland is cut into the Pleistocene limestone and, as such, illustrates classic rock shore geomorphic features of cliffs, stacks, benches, structural platforms, and notches, at the smaller scales, salt weathering and micro-pinnacles (Semeniuk & Johnson 1985). These geomorphic aspects of the geology of Muderup Rocks, while of some geoheritage importance, are not described/discussed further as the focus is on the (rock) geological features of the cliffs, i.e., the Pleistocene limestone that exposes the Pleistocene rocky shore, the Pleistocene unconformity, the Pleistocene beach to dune stratigraphy, and the diagenesis in the limestones.

The cliffs at Muderup Rocks expose four key geological features (Figures 8.46 & 8.47):

1. Pleistocene rocky shore cut into Pleistocene limestone, and its unconformable contact with younger Pleistocene sediments
2. Pleistocene beach to dune shoaling stratigraphy
3. Pleistocene desertic yellow sand unconformable on Pleistocene limestone
4. Pleistocene limestone diagenesis
5. An exhumed Pleistocene rocky shore platform that occurs as a rocky shore bench and simulates an earlier Holocene sea level indicator

The Pleistocene rocky shore cut into Pleistocene limestone, and its unconformable contact with younger Pleistocene sediments occurs in the lower part of the cliffs at Muderup Rocks. Based on information on rocky shores cut into limestones of the Perth Basin (Semeniuk & Johnson 1985; Brocx & Semeniuk 2009a), the key features of this part of Muderup Rocks are:
1. the basal limestone is a tightly cemented Pleistocene calcarenite that has rocky shore features cut into it; the erosional surface that constitutes the rocky shore surface is an unconformity between an older Pleistocene limestone and younger Pleistocene limestones;
2. the unconformity expressed as the rocky shore features cut into the underlying limestone include:
   (a) a roughly-horizontal erosional surface cut into indurated older limestone, (b) over-hangs, (c) decimetre-sized pot holes, (d) basins up to 2 m in size and up to 50 cm deep, filled with shell gravel, and coarse calcarenite;
3. bioerosion features that include centimetre-sized pholad borings into the unconformity surface, millimetre-sized network borings, submillimetre-sized sponge borings, and scalloped surfaces that are echinoid excavations;
4. shelly biota of rocky shore origin (including whole and fragmented gastropods *Ninella*, *Marmarstoma*, *Nerita*, *Littorina*, and abalone *Haliotis*; whole and fragmented bivalves *Barbatia*, *Austracochlea*, and *Brachidontes*; limpets *Collisella*, *Notoacmea*, *Patella*, *Patellanax*, *Patelloidea*, and *Siphonaria*; and barnacles; Semeniuk & Johnson 1985).

This sequence of rocky shore features at Muderup Rocks is uncommonly well preserved. The outcrop presents an excellent wave-washed and salt-weathered exposure of a wide variety of rocky shore features that illustrate processes and products during Pleistocene rocky shore development in terms of sequence, sedimentary structures, lithologies, and biological effects – it stands a model of rocky shore development for the Pleistocene globally. In this context, the site showing rocky shore features is of International Geoheritage significance.

The Pleistocene beach to dune shoaling stratigraphy occurs in the lower to upper part of the cliffs at Muderup Rocks. Based on information on beach to dune sequences of the Perth Basin described by Semeniuk & Johnson (1982) and Semeniuk (1997), the key features in this part of the sequence are:

1. a stratigraphic sequence, resting on the unconformity cut into older Pleistocene limestone described above, and some 5 m thick, that shows shoaling lithofacies from subtidal to dune;
2. the lithologies in the sequence that range from subtidal cross-bedded and festoon-bedded shelly coarse-grained calcarenite and coarse-grained calcarenite at the base to tidal swash zone lithofacies of seaward dipping medium-grained and coarse-grained laminated calcarenites and shelly calcarenites in middle parts of the sequence to medium-grained laminated calcarenite with bubble sand structure, to bioturbated medium-grained calcarenite with storm-level deposits of *Sepia* (cuttlefish bone) and *Spirula* (rams horn shell), and overlain by fine-grained macro cross-bedded calcarenite with landward dipping lamination representing coastal dune facies (Semeniuk & Johnson 1982);

This sequence at Muderup Rocks of Pleistocene rocky shore features is well-preserved. It is a geological feature that is locally occurring in Pleistocene limestones of the Perth Basin. For the whole of the Perth Basin, Semeniuk & Johnson (1985) only describe it locally along the coast at Trigg Island, North Beach, Marmion, Mullaloo, and Ocean Reef. Semeniuk (1997) describes it from a location in the Yalgorup National Park, and there is a small and incomplete outcrop at South Bunbury. As such, it is not commonly exposed in the Perth Basin. Moreover, of the recorded occurrences, the outcrop at Muderup Rocks is the best preserved and most complete.
Muderup Rocks also exhibits a structural rocky shore bench that has been interpreted as a former Holocene sea level indicator. It is an indurated bench with overlying (Pleistocene) beach deposits now exposed at 1.5 m above the present level of the rocky shore platform. It was interpreted by Fairbridge (1950) as a rocky shore platform cut into the Pleistocene limestones during (what was interpreted as) the mid-Holocene 5000 year BP 1.5 m sea level still-stand. However, the rocky shore bench is not one cut during a mid-Holocene 5000 year BP sea level still-stand but an exhumed Pleistocene rocky shore platform buried by Pleistocene beach/dune deposits and now exhumed by late Holocene erosion. The final stratigraphic array consists of a Pleistocene fossil rocky shore platform exhumed to form a bench 1.5 m above the modern rocky shore platform (Semeniuk & Johnson 1985) with a capping of beach deposit that is the lower part of the Pleistocene beach to dune sequence. Figure 8.48 illustrates the developmental history of the coast at Muderup Rocks and demonstrates that the mid Holocene platform interpreted by Fairbridge (1950) as indicating a 5000 year BP 1.5 m sea level still-stand is in fact an exhumed Pleistocene rocky shore feature.

The sequence at Muderup Rocks of beach to dune stratigraphy is well-preserved. It also is a stratigraphic sequence that is locally occurring in Pleistocene limestones of the Perth Basin. Semeniuk & Johnson (1982) describe it elsewhere in its full sequence from three locations on the northern Swan Coastal Plain (Muderup Rocks, northern Mullaloo, and Ocean Reef) and Semeniuk (1997) describes it from three locations on the southern Swan Coastal Plain (Tims Thicket Limestone and Kooallup Limestone in the Yalgorup National Park, and within the Kooallup Limestone in Lance’s Quarry). As such, it is not commonly exposed in the Perth Basin.

The sequence of Pleistocene rocky shore and the beach to dune sequence has not been described from equivalent Pleistocene limestones (the Bridgewater Limestone in South Australia and Victoria; Drexel & Preiss 1995; Birch 2003), nor from the eastern coast of Australia where Pleistocene limestones are absent. Similar well preserved and detailed Pleistocene rocky shores cut into limestone and stratigraphic sequences of Pleistocene beach to dune sequences in limestones have not been described elsewhere globally (cf. Semeniuk & Johnson 1985; Johnson 1988; Paskoff 2005). Muderup Rocks thus presents an excellent wave-washed and salt-weathered exposure of a combined ensemble of a Pleistocene rocky shore, the rocky shore to beach sediment unconformity, and the beach to dune stratigraphy that illustrates sequence, sedimentary structures, lithologies, and sedimentary processes and products – it stands a model of a rocky shore, the rocky shore to beach sediment unconformity, and the beach to dune carbonate sedimentation for the Pleistocene. In this context, the site is of International Geoheritage significance.

The Pleistocene desertic yellow sand unconformable on Pleistocene limestone occurs in the uppermost part of the cliffs at Muderup Rocks, and the Pleistocene diagenesis occurs throughout the limestone sequence. Based on information on yellow sand unconformably overlying Pleistocene limestone described by Semeniuk & Glassford (1987), the key features in the diagenesis of Pleistocene limestone and yellow sand relationship to the limestone at Muderup Rocks are (Semeniuk & Meagher 1981; Semeniuk 1983; Semeniuk & Johnson 1985; Semeniuk & Glassford 1987):
1. yellow sand 20 cm to 50 cm thick, overlies the limestones with unconformable irregular contact;
2. thick calcrite (1-10 cm thick) is developed along the unconformable contact impregnating the upper part of the limestone;
3. decimetre-sized pipes vertically cut through the limestone descending as deep as the lower beach deposits calcrite; these pipes are lined with calcrite; the pipes are also filled with yellow sand;
4. the inside of the pipes along their calcrite walls are lined by calcreted fine roots;
5. the limestone sequence of beach to dune is riddled with calcreted plant rhizocretions.

This sequence of yellow sand unconformable on limestone, the pipes penetrating the limestone, yellow sand infilling the pipes, the features of the calcrite linings and capping, and the calcreted rootlets are well-developed at Muderup Rocks. However, these are features quite ubiquitous along the coastally-exposed Pleistocene limestones of the Perth Basin (Seddon 1972; Semeniuk & Johnson 1985). Though not well developed in the Pleistocene limestones (Bridgewater Formation) of South Australia and Victoria (Drexel & Preiss 1995; Birch 2003), they are relatively common features when viewed globally. There have been descriptions of such features elsewhere in Western Australia and globally (Seddon 1972, Estaban & Klappa 1983; Semeniuk & Johnson 1985). As such the features of yellow sand and calcrite and their inter-relationships is a feature at Muderup Rocks that is of Local Geoheritage significance.

Discussion

This Chapter provided case studies of the application of the techniques of identification of features and assessment of features using the Geoheritage Tool-kit. In the case-study areas at the regional/large scales outlined above, the individual geoheritage components were not presented in isolation, as type locations, or best example of a given feature, but rather as integrated systems of geological products and processes-and-products. Hence, together, they form what can be termed a geopark. And given the important and unique nature of the areas, they qualify to be a National geopark (with features of International significance), thus integrating the various scales of geology and geomorphology into a single geoconservation unit since they contain numerous “geological heritage sites of special scientific importance” or geosites.

In the case-study areas at the small scale outlined above, the geosites, the individual geoheritage components, again, should be viewed not in isolation, as type locations, or best example of a given feature, but as the integrated system of geological products and processes-and-products though at a smaller scale. Thus, for example at Willie Creek, while individual facies can be determined as of geoheritage significance (e.g., the cyclone-deposited conglomerate, or the bubble sand structures), it is the ensemble of Holocene tidal zone stratigraphy and individual lithofacies as well as their stratigraphic relationships at this geosite that is of geoheritage significance. Similarly, while there can be focus on individual lithofacies and sedimentary rocks at the various other geosites, it is the ensemble of Mesozoic tidal flat stratigraphy and aggregation of individual lithofacies at Entrance Point, the ensemble of Pleistocene shoaling coral reef facies at Point Leander with the individual coral forms and internal structures of the coral reef frames, and the ensemble of Pleistocene rocky shore buried by a shoaling sequence of beach to dune sediments at Muderup Rocks that provide the importance of each of the geosites.

The theory underlying the allocation of an area to a geosite or to a geopark, based on complexity and/or inter-relatedness of geological features and on size, will be treated in more detail in the Chapters on Policy and Legislation.
In these case studies in Western Australia, with materials that range in age from Precambrian to Mesozoic to Pleistocene to Holocene, using an inventory-based approach, the Geoheritage Tool-kit has been applied to identify sites and features of geoheritage significance. Each of the geological features in the region or geosite identified in the inventory and identified within a framework of the broadest possible definition of geoscience was assigned a level of significance regardless of their scale. These case studies were wide-ranging in scope and scale of features: from large scale ria coats, to tide-dominated deltas, to barrier dunes and their leeward lagoons, to ria-type estuaries, and from mesoscale features such as dunes and tidal creek, to smaller scale features such as permineralised roots of rushes and calcrete features. At cliffs, the geosites were also wide-ranging from Mesozoic sandstones, to Pleistocene coral reefs and Pleistocene rocky shore and beach/dune sequences, to Holocene tidally deposited sands.

The Geoheritage Tool-kit provides a method to give context to a range of inter-related smaller features such as those found, for instance, in King Sound (the crustacean fossils, or the mangrove stumps), and in the Leschenault Peninsula and leeward estuarine lagoon (the permineralised sea rush, or the calcrete) because there is a need not only for geoconservation of large scale features but also of significant smaller scale features in these systems.

Geoconservation involves conservation of individual smaller scale features as well as integrated geoconservation that preserves the geological setting and the surrounding geological suite as an inter-related ensemble. Thus in terms of geoconservation, addressing the various features of geoheritage value along the Kimberley Coast, in King Sound and in the Leschenault Peninsula area and its associated estuarine lagoon is best achieved by viewing the system holistically as an integrated (geo)park of interactive processes, geology, and geomorphology. Therefore, given this background and the important and unique nature of these areas, it should be viewed as a National or State geopark, within which there also are features of International significance, thus integrating the many smaller-scale features of geology and geomorphology into a single geoconservation unit. King Sound and its tide-dominated delta and the Leschenault Peninsula and its associated estuarine lagoon qualify in containing numerous “geological heritage sites of special scientific importance”. The various components of the geoheritage of these areas should be viewed not in isolation, as type locations, or “best example of a given feature”, but as the integrated system of geological products and as integrated systems of processes-and-products. Landscape evolution in the Leschenault Peninsula barrier dune is an example of these principles. For the four different areas, calcrete, intra-estuarine deltas and their asymmetry, peripheral wetlands, dunes of the barrier system, and the distinctive and complex estuarine shore stratigraphy, amongst the many geological features inherent to a given specific area, also provide examples. The fine and very fine scale features, such as calcitisation of sea rush roots by encrustation/ perminerisation under the high tidal flat at along the shores of Leschenault Peninsula, that is dependent on the groundwater seepage from the adjoining dunes, provide specific example of these principles, in that without the calcite-bearing dune sand, the parabolic dune encroaching into the estuary, and the nature of the dune sand to estuary hydrology, there would not be the calcitisation of the roots of the sea rush. The International significance of the calcitised roots of the sea rush needs to be addressed by not only preserving the calcitised sea rush roots but also the dune terrain, dune stratigraphy, and dune-to-estuary hydrology all of which sustain the calcitisation process.

Successful application of the Geoheritage Tool-kit at the regional, large, and small scales at eight locations along coastal Western Australia suggests it can also be applied to inland Western Australia (e.g., Precambrian terranes of the Pilbara region), and that it could have world-wide applicability. It has also been applied to the Anti-Atlas of Morocco in northern Africa (Errami et al., 2013, 2014) to identify sites of geoheritage significance as a basis to assigning them to geosites and geoparks. The corollary is that the Geoheritage Tool-kit can applied to any geological site, or region, of any age, to determine geoheritage values for conservation and management.
Chapter 9: Policy and Legislation in relationship to Geoheritage and Geoconservation - some definitions and their relevance to Geology/Geoheritage

From the 1970s, community concern in relation to environmental issues led governments around the world to create a suite of environmental policy and regulatory instruments for the conservation, protection and management of the environment, and the protection of human health. This involved establishing legally enforceable legislation with environmental thresholds in relation to waste management, noise control, and land, water and air pollution. Rachel Carson (1962), an advocate of nature and environmental ethics, in her seminal publication, *Silent Spring*, was instrumental in adding weight to the body of concern over the long-term environmental impacts, and effects on human health due to the unregulated use of pesticides. Since then, in the arena of conservation governance, it has been the protection of flora and fauna, *i.e.*, the biotic, that has been the focus for funding and developing parks and wildlife government agency infrastructure. This is because most policy and legislative instruments globally and in Australia are derived from top-down processes as an outcome of being a signatory to various international treaties or conventions with governments establishing statutory frameworks to meet the objectives and obligations of those conventions. With the notable exception of the World Heritage Convention (1972), environmental conventions largely relate to the protection of flora and fauna in the terrestrial and marine environment. Conventions to which Australia is a signatory form the basis for Australia’s environmental protection frameworks; these include the Ramsar Convention (1971), the World Heritage Convention (1972), and the Convention on Biological Diversity (CBD, 1992).

As noted in Chapter 1, the objectives of the Chapters on policy and legislation to follow ultimately are to develop a policy framework for coastal geoheritage/geoconservation in Western Australia using a science-based approach to select, preserve, and manage sites of geoheritage significance for geoconservation. The aim of the reviews was to determine whether there are opportunities for incorporating the conservation of coastal geoheritage within existing policy frameworks, or whether there is an existing framework for the protection of biota which could be used as a policy template. A historical approach was undertaken to review:

1. a range of terms in policy and legislation associated with environment, environmental protection, and heritage that may/can underpin notions of geoheritage and geoconservation;
2. the theory and philosophy underpinning policy and legislation as they relate to environment, geoheritage and geoconservation;
3. the existing approaches to geoheritage and geoconservation in key regions;
4. the history of and existing approaches to geoheritage and geoconservation in Australia;
5. existing instruments for geoheritage and geoconservation policy in Australia; and
6. existing instruments for geoheritage and geoconservation in Western Australia;

The reviews were undertaken to ascertain the meaning and intent of policies and legislation, and whether their scope and subject matter directly or partially cover the conservation of geology and sites of geoheritage significance, and to determine if they need to be modified where the opportunities for such amendments exist.

Policy and legislation in general, and even policy and legislation as they relate specifically to geoheritage and geoconservation are large fields of study, with an extensive body of literature. A comprehensive and exhaustive treatment of this subject matter is beyond the scope of this Thesis. Accordingly, after discussion of principles and definitions in succinct manner in this Chapter, examples of policy and legislation relating to Geoheritage and Geoconservation will be treated
selectively in the next Chapters, focusing on the British Isles, the United States of America, Portugal, some States of Australia including Western Australia, highlighting those aspects of policy and legislation that more directly relate to geological matters.

Key definitions are discussed first because there is a wide range of meanings associated with many of them in the field of policy, environmental policy, environment, and legislation and, in particular, environmental policy and legislation. The remainder of this Chapter thus reviews a range of terms associated with environment, environmental protection, and heritage and assesses their applicability to geology, geoheritage, and geoconservation. These terms are relevant because they may or can underpin notions of geoheritage and geoconservation. However, it should be noted that while the terms to be defined/discussed below are well established in the literature, they may have different meanings in different disciplines and in different countries. The key words are:

Environment
Nature – biotic nature, abiotic nature
Heritage
Policy
Environmental policy
Environmental law and legislation
Planning

Environment
The term environment is well established in the literature but it is an example of a word with a multiplicity of meanings depending on discipline, human involvement, and legislation. Where defined explicitly, it ranges from the natural environment (the biophysical environment), to human-managed systems (e.g., agriculture), to the built environment (such as cities, and urban areas), to social environments (e.g., cultural settings). In science, it may be used to denote the total surroundings of landscape, soil, water, and air at the large scale with or without reference to its effect on or relation to biota (the ecosystem; Haeckel 1866 in Stauffer 1957), or it may be used to denote features, attributes, and qualities at small scales (such as the interstices of sand as the environment for hydrochemical reactions, or micro-habitat for diatoms), again, with or without reference to its effect on or relation to biota. Generally, however, the involvement of or effect upon humans and biota is captured in most definitions of environment.

In environmental law, Tyler (1995) uses the term environment to mean the total surroundings of landscape, soil, water, and air but in a framework that has relationship to humans and biota. For Thomas (2007), the term environment integrates land and sea, air, natural resources, plants, animals, landscapes, and urban open spaces, referring to the bio-physical parts of the Earth, and includes humans as part of the environment. Caldwell (1996), in dealing with international environmental policy, presents this meaning of environment: “As commonly used, ‘environment’ usually means surroundings. In fact, the term is more complex. In one of the better dictionary definitions, ‘environment’ is ‘whatever encompasses; specifically the external and internal conditions affecting the existence, growth, and welfare of organisms’. Thus ‘environment’ includes both that which environs and whatever is environed .... more precisely the living world or biosphere including the human species. Thus ‘environment’ most accurately denotes the relationship between the environing and the environed.” In discussing environmental issues, Caldwell (1996) recognised that humanity historically was more concerned with resource exploitation and national interests than with conservation of the global environment but, for global environmental policies to be formulated, the interactive life-sustaining processes of the whole biosphere had to be acknowledged. In discussing environment, Caldwell (1996) did not address geology and geoconservation either for geology and geoheritage per se nor as the physical/chemical basis that underpins the biosphere.
In contrast, Vernadsky (1927) related the biosphere to the abiotic world: “In everyday life one used to speak of man as an individual, living and moving freely about our planet, freely building up his history. Until recently the historians and the students of the humanities, and to a certain extent even the biologists, consciously failed to reckon with the natural laws of the biosphere, the only terrestrial envelope where life can exist. Basically man cannot be separated from it; it is only now that this indissolubility begins to appear clearly and in precise terms before us. He is geologically connected with its material and energetic structure. Actually no living organism exists on earth in a state of freedom. All organisms are connected indissolubly and uninterruptedly, first of all through nutrition and respiration, with the circumambient material and energetic medium. Outside it they cannot exist in a natural condition.” This clear connection between abiotic and biotic proposed by Vernadsky (1927) makes a strong case that environmental policy and law need to address the abiotic realm.

In an Australian context, Fisher (2014), following Villancourt (1995), considers the environment to be an organised, dynamic, and evolving system of natural (physical, chemical, biological) and human (economic, political, social, cultural) factors in which living organisms operate or human activities take place, and which has a direct or indirect, immediate, or long-term effect or influence on these living beings or on human actions at a given time and in a circumscribed area. Geology and sites of geoheritage significance are not recognised. As can be ascertained above, the abiotic elements within the concept of environment in environmental law are generally those that can have impact on human health, biota, and ecosystems. This has been documented by numerous authors, and there have been many acts, laws, legislation, protocols and treaties enacted to control and regulate effects on environmental quality and safeguard human health. As such, the environment is viewed as that which supports humans and their food production, ecosystems that are of benefit to humanity and, at the other extreme, ecosystems and biota that have intrinsic value in themselves (e.g., iconic, or rare and endangered flora and fauna). Focus also has been on protecting the environment to protect ecosystems where pollutants are damaging to ecological communities or endangered species. Though often not expressed explicitly in most textbooks and journal papers on environment and environmental law, the underlying tenet is implicit: environmental law is oriented towards protecting human health and ecosystems. Geology as cliff faces, monoliths, and a vast variety other geological phenomena such as impressive outcrops, folds, faults, minerals, fossils, and lithologic sequences, important to science and to Earth scientists, are outside the definition of environment, even though belonging to the realm of the abiotic. To provide an example of this notion: a quarry excavated for building materials, extending some tens of metres in depth and exposing subsurface material for the first time, is not considered an environment necessarily worthy of protection and management and, if it is not generating dust or affecting the groundwater, will not fall within the net of environmental law, nor within the scope of needing protection as an environment. During its operations, if it were to be found to contain well-preserved and scientifically important dinosaur fossils or rare fish fossils, the quarry may be preserved on scientific grounds, but not on an environmental basis.

The connection between abiotic and biotic, advanced decades ago by Vernadsky (1927) that geology is the basis of support for biotic systems, generally was not and largely still is not in mainstream thinking in environmental policies and law. Environmental policy and law do not address the importance of geology and the matter of features of geoheritage significance. In this context, environmental policies and laws will not necessarily result in the conservation of geology per se and features of geoheritage significance. Rather, geology is given importance as a natural resource for economic exploitation, or as a component of sustaining life in a holistic ecosystem approach to protected areas management.
Because of the inconsistency in the use of the word environment within and across disciplines, and to distinguish between human-built and human-managed environments and the natural world, some authors use the term natural environment. Johnson et al. (1997) attempted to rationalise the term natural environment, defining it as follows: “a natural environment is one relatively unchanged or undisturbed by human culture. It thus logically follows that a non-natural environment is one that is relatively changed, modified, disturbed, or created by our cultural activities”. The natural environment thus encompasses all living and non-living things occurring naturally on Earth.

In all this range of definitions of environment and environmental law, and concern with managing environments for protecting human health and food production and ecosystems, it is noted there is little or no mention of geology, geoheritage, or geoconservation as the basis for environmental protection and environmental management. And there is also no mention of protecting features of geology sensu stricto or sites of geoheritage significance.

The definition of Johnson et al. (1997) is followed in this Thesis and, if used as a term in isolation, the term environment will denote natural environment. Where the environment is not natural, the term man-modified environment and artificial environment will be used.


The term nature sensu lato, as used in many disciplines of science, refers to the natural, physical, or material world or universe wherein processes and products are naturally occurring or that have formed naturally without human intervention or management. Thus, nature can refer to the features of the physical and chemical world, and also to life and biotic processes in general. In terms of scale, it can range from the cosmic to the subatomic, as long as the processes and products are naturally occurring and not man-made nor man-managed.

The term nature sensu stricto commonly refers to the wild, untamed and unmanaged areas of the Earth encompassing landscapes where natural vegetation and fauna and processes are allowed to operate without human intervention. Here, nature is viewed as abiotic (i.e., physical and chemical processes and products such as rocks, water, air, chemicals, volcanoes, storms, wave action, amongst innumerable others) or as biotic (i.e., biological systems of species, communities, ecosystems, and their interactions with habitats). In reality, abiotic nature and biotic nature are intertwined - biotic nature cannot exist without abiotic nature; for instance, rocks interact physically and chemically with other abiotic components such as water, air, and chemical species and produce soils and habitats, and habitats form the home for biota.

However, to date, environmental law and environmental protection have been focused on nature from a biological viewpoint - that is, the protection of nature in terms of species and communities. And while the protection of the abiotic realm in recent times is addressed somewhat in the conservation of habitats, the emphasis had been on protection of habitats with the objective of protecting species and communities. The history and initial objectives of the International Union for the Conservation of Nature (IUCN) provide an example of this.

Founded in 1948 with the objective to conserve biological systems, the IUCN is the World’s oldest and largest global environmental organisation. It is a neutral forum for governments, NGOs, scientists, and business and local communities to collaborate and endeavour to find practical solutions to conservation and to develop policy, laws and best practices. In 1978 a decision was taken by the IUCN to develop a category-based system for protected areas. In 1994, a protected area was defined as being “An area of land/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means” with six categories of protected areas. Although the conservation of biodiversity was
central to its mission, there also were areas designated to be managed mainly for conservation of natural features, such as Natural Monuments, and designated landscapes and seascapes for scenic values (IUCN and WCMC 1994), and there was an emerging (global) paradigm where protected areas were established for scientific, economic and cultural reasons (Lockwood and Kothari 2006).

In keeping with this finding, in 2008 the IUCN redefined its definition of “protected area” as being “A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.” Refined over several years of negotiations, the definition was intended to apply to all types of protected areas: terrestrial, freshwater, coastal, and marine (MPA 2008). For Australia, that uses the six IUCN protected areas categories (IUCN 2008), axiomatically, the term nature now includes geology.

Also in 2008, sponsored by ProGEO (the European Association for the Conservation of Geological Heritage), the Commission on Geological Heritage of the Geological Society of Spain, was successful in presenting a resolution called “Conservation of geodiversity and geological heritage” to the General Assembly of the IUCN at the Fourth World Conservation Congress (IUCN 2008; Díaz-Martínez & Guillén-Mondéjar 2009; Díaz-Martínez 2012). This resolution was adopted, and was the forerunner for further resolutions passed at the World Conservation Congress at its session in Jeju, Republic of Korea in 2012 (viz., WCC-2012-Res-048-EN Valuing and conserving geoheritage within the IUCN Programme 2013–2016). The resolution resulted in geoheritage being added as a category on the Global Protected Areas Programme, and establishing the IUCN WCPA Geoheritage Specialist Group.

These events, and the European Landscape Convention in 1998 (Buergi 2002) that recognised the need to protect landscapes by integrating geoconservation philosophy into regional and town planning policies, have significantly increased the understanding of the importance of geodiversity (and hence geology and geoheritage) and resulted in actions to arrest the loss of irreplaceable geological heritage. It was an attempt to avoid the continued loss of The Memory of the Earth (International Declaration of the Rights of the Memory of the Earth; Martini 1993).

With these developments, the definition of Nature in the IUCN was expanded to explicitly include ‘Geology’ (essentially in the wording “that geological heritage constitutes a natural heritage of scientific, cultural, aesthetic, landscape, economic and/or intrinsic values, which needs to be preserved and handed down to future generations”). The text of the resolution that was adopted by IUCN explains that geodiversity is the natural diversity of abiotic elements, features and processes, including minerals and rocks, fossils and meteorites, landforms and surface deposits, groundwater, and fossil energy resources.

The recognition of geology, geoheritage, geoconservation, and geodiversity within the IUCN progressed further in 2014. At its decennial congress for World Parks (the 6th IUCN World Parks Congress) held in 2014 in Sydney (Australia), through activities and lobbying of the Geoheritage Specialist Group within the World Commission on Protected Areas of the IUCN and, in collaboration with ProGEO, the Geological Society of Australia, and the Wetlands Research Association (in Western Australia), for the first time in its history the IUCN accepted sessions and contributions within the Congress that focused on geoheritage/geodiversity. This further consolidated the role of the IUCN in protecting and conserving sites of geoheritage significance and protecting areas of geodiversity. In essence, at the 6th IUCN World Parks Congress, the IUCN recognised that geodiversity underpins and is responsible for biodiversity, and in protecting geodiversity it is protecting biodiversity.
The word *nature* is also addressed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in its identification and inscription of World Heritage Sites (UNESCO 1972). In terms of the Convention outlined in its 1972 document, Natural Heritage follows this usage:

1. natural features consisting of physical and biological formations or groups of such formations, which are of outstanding universal value from the aesthetic or scientific point of view;
2. geological and physiographic formations and precisely delineated areas which constitute the habitat of threatened species of animals and plants of outstanding universal value from the point of view of science or conservation; and
3. natural sites or precisely delineated natural areas of outstanding universal value from the point of view of science, conservation or natural beauty.

From these perspectives, from the view of IUCN, the term ‘nature’ is now extended to include geology, and laws that protect nature can be extended to protect features of geology (Crofts & Gordon 2015). This is particularly relevant where Australia is a party to programmes associated with IUCN where there is requirement to protect nature that now includes geology.

**Heritage**

The term heritage in the broadest sense refers to that which is inherited. More definitive meanings are:

1. that which is inherited and has some economic, spiritual, intellectual, educational, emotional, or aesthetic value (Kellert 1996; Avrami et al. 2000; Munoz-Vinas 2005; Anon 2014b), or 2. “denoting or relating to things of special architectural, historical, or natural value that are preserved for the nation” (Oxford English Dictionary 2014).

Of relevance here are the definitions of heritage that distinguish between *natural heritage* and *cultural heritage* in that the former can be applied to geological features and the latter, though generally emphasising man-made artifacts and structures, can also refer to natural and man-modified geological features that have been incorporated into local culture e.g., monolithic outcrops that are part of indigenous spiritual beliefs, such as Karlwe (the Devil’s Marbles) in the Northern Territory (Wyche et al. 1986); and ancient mine sites representing historical use of mineral resources such as at the Isle of Elba (Pezzotta et al. 2005).

In environmental science, and natural environments, heritage usually refers to unspoilt natural areas, to the evidence of the past, such as historical sites, buildings, and to palaeontological deposits, all considered collectively as the inheritance of present-day society (Kellert 1996; Avrami et al. 2000). The UNESCO World Heritage programme, while not explicitly defining heritage *per se*, provides implicit meaning of the term in its definitions of cultural heritage and natural heritage in that the descriptions are ostensive or demonstrative (Copi 1982).

In Australia, the issue of heritage is defined and treated in the Department of Sustainability, Environment, Water, Population and Communities wherein one of the Administrative Portfolios deals with natural, built and cultural heritage (Lennon 2006). The Australian Federal Government defines ‘heritage’ as (Anon 2013) “... all the things that make up Australia's identity - our spirit and ingenuity, our historic buildings, and our unique, living landscapes. Our heritage is a legacy from our past, a living, integral part of life today, and the stories and places we pass on to future generations”.

Globally, while cultural and natural heritage are reasonably dealt with and defined in the literature, there are other aspects of heritage that, although generally known and discussed, have not been extensively explored. These are the heritage of knowledge such as that stored in libraries or maintained in traditional cultures, the heritage of museums, the heritage of history, the heritage of buildings, and the heritage of the archive, or the book of the Earth.
Knowledge as heritage is the first example. It is an intangible facet of heritage, and it is present as oral traditions, or stored in books in libraries, or present in the communities of indigenous peoples. The focus in this Thesis is on libraries (Aabo 2005a; Zickuhr et al. 2013) and on indigenous knowledge (Battiste & Wiessner 2002; Battiste 2005). In any case, it is accepted that knowledge as heritage requires protection and to this objective libraries as the store-house of knowledge are valued in the community (Aabo 2005a, 2005b; JLMS 2008; Mainka et al. 2013; Zickuhr et al. 2013). The same can be said of museums (Kurin 2004; Museums Australia 2009; Kamps & Weide 2011; Weide 2011) – they are store-houses of information and knowledge, and valued by the community as heritage assets (Dolan 2007).

Human history is embodied in oral traditions such as stories and song, or represented in archaeological records (buried ancient building ruins, buried artifacts, ancient artwork, tumulus burial mounds, shell middens, and charcoal hearths), or represented by historical art and sculptures. Here, history as heritage can overlap with the cultural and heritage value of libraries, museums, and with some of the sciences such as geology and archaeology. Humanity has valued such interests, and has endeavoured to protect/preserve these expressions of human history as heritage. UNESCO’s identification and protection of historical features and ancient buildings as World Heritage Sites exemplify this. And at National levels, historic buildings dating from the 18th and 19th centuries are often viewed as heritage sites (e.g., the Kremlin Senate building, and Old Parliament House in Canberra, Australia).

History as heritage also is embodied in geology in that geological features record the history of the Earth. For instance, the Grand Canyon in Arizona stratigraphically records Earth history from the Precambrian through lower Palaeozoic to the upper Palaeozoic, with unconformities, and records the geomorphic evolution of the terrain from a riverine plain with a meandering river to an uplifted plateau deeply incised by that same meandering river (Holmes 1966; Shelton 1966; and discussed in Brocx 2008). The region is a globally important classroom for the aspects of megascale geomorphology and tectonism, local stratigraphy and stratigraphic relationships, and modern riverine processes. Muderup Rocks, the geosite described in Chapter 8, provides a record of Earth history, at a smaller scale, within the Pleistocene in a coastal sedimentary setting. The geosite is a globally-important classroom for the aspects of Pleistocene and modern rocky shore geomorphology and sea-level history, and local stratigraphy and stratigraphic relationships of shoaling beach/dune sequences.

The final aspect of heritage focuses on geology as a reservoir of information from which the history of the Earth and of life can be read. Geology effectively is the library of the Earth, as articulated in the Memory of the Earth (International Declaration of the Rights of the Memory of the Earth; Martini 1993) mentioned early. From this perspective, geology and sites of geoheritage significance are analogous to libraries and museums in that they are natural reservoirs of stories of the Earth. Spanning a record of 4.5 billion years, the Earth provides a library of information about Earth evolution, Earth processes, the development and evolution of life, and a host of physical and chemical processes/products at scales of mountain ranges to that of crystals. If the knowledge reservoirs of libraries and museums are of heritage significance, the same perspective should logically be afforded geology and sites of geoheritage significance.

Thus it is within the realm of heritage that geology and sites of geoheritage significance, if they are to be protected, can be conserved.
Policy
Policy can mean agenda, or vision, guidance, objectives, or a set of principles. To provide a framework on how to achieve these objectives, a review is presented in the next Chapters of policy and legislation in various parts of the World where there are such instruments in regard to geoheritage and geoconservation, and particularly in regard to coastal geoheritage and geoconservation.

In this Thesis, the term policy for coastal geoheritage and coastal geoconservation is defined at four levels (to be described and discussed in Chapter 11): as a philosophy of approach, and as guidance. Firstly, policy is defined as an umbrella concept, or philosophy of approach, or a position statement that there is need for recognition of coastal geoheritage and geoconservation within Western Australia in its framework of nature conservation at the Legislation level. Secondly, it is presented as guidance that the Geoheritage Tool-kit can be applied to coastal Western Australia to systematically identify geosites and geoparks. Thirdly, policy is provided of generalised principles of actions and procedures to be followed for the range of geosites and geoparks. Fourthly, policy is provided of a more practical and detailed outline of methods to apply principles of geoheritage and geoconservation and geo-management that may differ at the site-specific level varying depending on geological region, type of information at a site, and type of location.

Environmental Policy
Depending on author, environmental policy essentially is viewed to be a series of objectives, guidelines, plans, or formal objectives, strategies, outlines of programmes, agenda, or a vision to achieve a positive or desirable outcome in the area of the protection and/or management of the environment (as defined above). These policy formulations occur within time scales that, at one extreme, coincide with the life of a political party that may be drafting the policy or, at the other, over a longer timetable that accord with the interests of the Nation or State. Environmental policies could mean the formulation of plans to implement actions and management plans, for instance, to improve local estuary water quality, or reduce air pollution, or reduce salinisation, or decrease the rate of loss of, and reverse the loss of, biodiversity. Environmental policies generally work towards achieving environmental quality.

Environmental policy can be dealt with at different scales, e.g., globally or locally. Global issues of environmental degradation clearly need to be addressed with international co-operation. For instance, the matter of CFCs causing breakdown of the ozone layer, or the loss of habitats for trans-equatorial migratory avifauna, and the over-fishing in the oceans affect global environments and global communities need to be addressed with international co-operation. In such circumstances, where it has been determined that there is indeed a global problem, the global community has galvanised to remedy or manage the problem. Local issues are focused on environmental degradation that does not emanate beyond a specific region. The pollution of an estuary and its impact on plant and animal life therein, or the contamination of food by heavy metals deriving from a point source, while unacceptable or even injurious to local human and animal populations, are localised phenomena not global in effect. Such local impacts are managed by locally-designed environmental policies and management plans.

Caldwell (1996) comprehensively outlines the history, the underlying philosophy, scope, and outcomes of global environmental policies. Global environmental policies and management effectively began in 1972 with the Stockholm Conference on the Human Environment that marked the culmination of efforts to place protection of the biosphere within the realm of International Policy and Law. The two decades following the Stockholm Conference saw great advances in international acceptance of global environmental policies, though Caldwell (1996) proffers that much of the advances were rhetorical, vīz., declared intentions that were not immediately honored. But the
principal accomplishments of the Stockholm Conference were twofold: firstly, official recognition that the problems of the environment were of international concern and, secondly, institutionalization of the concept in the United Nations Environment Programme (UNEP). Caldwell (1996) also contends that although some of the declarations were “rhetorical”, the action of becoming a signatory to a treaty eventually led to many nations acceding to the spirit and letter of the commitment. After the Stockholm Conference, the next international meeting on global environmental issues was the Conference on Environment and Development in Rio de Janeiro in 1992. The Rio de Janeiro Conference built on and advanced the outcomes of the Stockholm Conference and legitimised environment as a focus for international environmental policy. All these policies are to save the planet Earth biologically. Subsequently, the World Summit on Sustainable Development in 2002 (informally named "Rio+10"), 10 years after the first Earth Summit in Rio de Janeiro, focused on people issues and on biologically restoring the World's depleted fisheries, while the United Nations Conference on Sustainable Development in 2012 (informally named "Rio+20"), focused on sustainable development and attempted to define “green economy”.

In environmental policy at the global scale, and focused on perceived global issues, the international community has highlighted and acted on environmental problems that they held in common (viz., atmosphere pollution, ozone depletion, acid rain, effects of green-houses gases, sea-floor mining), and strived to obtain a consensus for management at the global level (Caldwell 1996). The spotlight in global environmental policy and management covered in the United Nations Environment Programme (UNEP) or in the Conference on Environment and Development was on biological, hydrochemical, aerochemical and deep-sea resource depletion, with their effects on biota and ecosystems. There was no recognition of the requirements of geodiversity or geoheritage at these conferences.

In environmental policy at the local scale, and focused on perceived local to regional issues, the local, State, and National bodies in a given country have highlighted and acted on environmental problems such as canal development, containment of chemical contamination, coastal erosion, the effects of dredging and dredge spoil disposal, and nutrient enrichment, amongst others. There are innumerable examples of local environmental policies and management plans around the world, but a series of examples for the Western Australian coastal setting dealing with issues such as canal estates, coastal set backs and coastal management, dredging, sediment management, nutrient management, and heavy metal management are referenced here (Wulf & Baird 2006; Department of Water 2007; 2008; Swan River Trust 2008; City of Mandurah 2009, 2012; Western Australian Planning Commission 2012). Similar to the global examples, there was no focus on geology in these locally-developed and State-developed environmental policies and management programmes.

From the above, it is evident that geology and sites of geoheritage significance generally are not mentioned in environmental policies at the global scale, and neither is there a focus on geology and sites of geoheritage significance in environmental policies at the local scale.

Environmental Law and Legislation
Fisher (2014) views law as an artificial creation of the human intellect, regardless of whether a rule of law is a recognised custom handed down by word of mouth or whether it assumes a written form such as a constitution or a statute. Contemporary urbanised and industrialised societies tend to recognise or create rules of law in written form even where their function is to recognise and give effect to customary law. The traditional function of a legal system has been to set standards of human behaviour and to set procedures and increasingly, standards, of decision-making, with the values of society emerging only indirectly through these functions. In relation to environmental law, Fisher (2014) views that the function of the law requires recognition of the special features of environment and, in particular, a recognition of the damage to the environment caused by human activities. The causes and effects of environmental damage due to chemical pollution, nutrient enrichment, ozone
depletion, and climate change, to name a few examples, are proving to be major challenges for environmental law. It is thus the nature of environment and environmental damage that has, over the last few decades, forced legal systems to introduce rules, standards, procedures and sanctions appropriate to the subject matter of environment (Fisher 2014). However, environmental law in these contexts, following the definition of environment that Fisher (2014) has adopted, is focused on impacts on biotic environments and impacts on humans. Environmental law here does not address the protection of geology sensu stricto and sites of geoheritage significance.

In a review of environmental law globally, with a focus on the United States of America, the United Kingdom, South Africa, India, China and Bulgaria, Fisher (2014) documents that generally the definition of environment encompasses landscape, water, air, and even buildings and man-made structures and their interaction and effects on humans and biota. There is an emphasis on the well-being of biota and humans, and hence environmental law generally is structured to this objective. The exception is Bulgaria where there is reference to damage to the environment in terms of culture, history, and landscape, but not to a level that explicitly includes geology or geoheritage significance.

In dealing with environmental law as noted above, Sands & Peel (2012) accept that environment refers to atmosphere, atmospheric deposition, soils and sediments, water quality, biology and humans and contend that legal definitions of environment reflect scientific categorisations and groupings, as well as political Acts that incorporate cultural and economic considerations. Scientific definitions are transformed by the political process into the legal definitions found in treaties; although 'environment' does not have a generally accepted usage as a term under international law, many agreements identify the various media included in the term. As such, the approaches to defining the 'environment' vary. For instance, early treaties tended to refer to 'flora and fauna' rather than the environment, thus restricting the scope of their application. In any case, aspects of geology are not included.

Benidickson (2013) considers that environmental law is related to regulation and policing of the environment where it concerns the effects of climate change, and the effects on biodiversity, clean water, clean air, and impacts from pollution on human health (Anon 1956; Environmental Protection Authority USA 2013). Breaching environmental laws is argued by Benidickson (2013), if injurious to human health and societies, is equivalent to criminal law (i.e., environmental impacts and criminal impacts both harm humans). Clearly, in such a context, environmental law can not be extended to include the protection of processes and products that are geological in nature. Destruction of a cliff face for building materials or its mineral wealth where that cliff face contains fossils, or minerals, or a scientifically significant stratigraphic sequence is not injurious to humans and, in fact, may benefit humans in that it provides resources for exploitation. From this perspective, environmental law largely does not protect the abiotic environment per se but rather ensures the abiotic environment does not harm humans, ecosystems, food resources, or non-human species. As such, it does not seek to protect geology sensu stricto, i.e., cliffs, fossils, minerals, and other scientifically-important geological phenomena.

Effectively, environmental law at global level and at local levels fails to address conservation and management of geology and sites of geoheritage significance.

Planning
Planning in the arena of policy development includes environmental planning, land-use planning, urban planning, and regional planning (involving, for instance, strategic plans for infrastructures such as arterial roads and energy supply corridors, or large-scale land-use, or rationalisation of demography, amongst other issues). Planning can involve actual ‘spatial planning’ (i.e., the physical design and allocation of the arrangement of real objects and materials in a spatial framework), or ‘abstract planning’ (i.e., procedures, actions, and plans in the abstract), or involve abstract planning that spills over into and manages spatial systems.
Planning theory is generally called a ‘procedural process’ because it concerns itself with the process through which the planning occurs and whether or not that process is valid. Lane (2005) traces the intellectual history through its different procedural approaches, especially as they relate to public participation.

As a profession, planning uses knowledge from the natural sciences (e.g., to plan roads and the physical layout of cities), uses knowledge from the social sciences (e.g., to understand the social implications of a new road), and aims to provide a contribution on what, when, how, and why to undertake an action or plan (Pløger 2001; Ferreira et al. 2009). It is also a discipline that is subject to flux, much in the same way that Kuhn (1970) describes the paradigm shifts in science (Ferreira et al. 2009) and, as such, planning has varied in time responding to changes in social norms and scientific information. For example, the increase in knowledge about environmental impacts on water systems has changed the manner in which urban systems and their impacts on waterways and groundwater are managed (Lloyd et al. 2002; Roy et al. 2008). In the field of geoheritage and geoconservation, new knowledge about the importance of such geology and geoheritage has changed the manner in which developments progress and how outcrops are used (Bennett et al. 1996; Larwood & Page 1996; Rodrigues et al. 2011; Palacio-Prieto 2014).

The theory of planning as it relates to business, administration, governance, and government is covered by Montana & Charnov (1993, 2008) and in a series of papers by Barnett & Hack (2000), Berke et al. (2000), Garcia et al. (2000), Hoch (2000), Myers & Menifee (2000), and Thomas & Grigsby III (2000) in Hoch et al. (2000) dealing with the practice of Local Government planning. In planning, Montana & Charnov (1993, 2008) define and identify the planning notion itself, the formulation of strategy in planning, the implementation of strategy in planning, the basic concepts of organising, management of information systems, and the scale at which management is undertaken. Defined and examined in more detail, planning involves the design of strategies and actions to achieve missions and objectives. For practical and efficient planning, in this Thesis, four steps are identified (modified and augmented from the three steps presented by Montana & Charnov 2008):

1. selecting an objective;
2. designing routes to achieve the objectives;
3. evaluating alternative routes or methods to achieve the objectives; and
4. deciding on a specific course to achieve the objective.

Lane (2005) describes four central elements in what is known as synoptic planning (as distinct from blueprint planning) which overlap with the three steps suggested by Montana & Charnov (1993, 2008); they are: 1. an enhanced emphasis on the specification of goals and targets; 2. an emphasis on quantitative analysis and predication of the environment; 3. a concern to identify and evaluate alternative policy options; and 4. the evaluation of means against ends. Blueprint and synoptic planning both employ what is called the rational paradigm of planning.

The rational model is perhaps the most widely accepted model among planning practitioners and scholars, and is considered by many to be the orthodox view of planning (Lane 2005). The objective of this model is to make planning as rational and systematic as possible and, in this context, it is the logical one to use in planning policy. Proponents of this paradigm would generally come up with a list of steps so that the planning process can be at least relatively neatly sorted into and that planning practitioners should go through in order when setting out to plan in virtually any area (Lane 2005). As noted above, this paradigm has clear implications for public involvement in planning decisions, and is relevant to planning for environmental purposes, conservation purposes, and the rational design of environmentally-appropriate urban and industrial land-use.
For geoheritage and geoconservation, planning a policy or a pathway to achieve a policy, will involve the four steps mentioned above, viz., 1. selecting objectives; 2. designing routes to achieve objectives; 3. evaluating alternative routes to achieve objectives; and 4. deciding on a specific course to achieve objectives, and these four steps are applied to each of the aspects of policy that are to be designed for geoheritage and geoconservation at a given site or region.

Summary
The critical arenas whereby geology, geoheritage and geoconservation can be addressed in conservation, protection, policy and legislation are nature and heritage. Strictly, the definition and usage of the term environment and hence environmental law and legislation and environment policy do not cover geology, geoheritage and geoconservation. The terms policy and planning and their functioning are applicable to the matters of geology, geoheritage and geoconservation.
Chapter 10: Policy and Legislation in relationship to Geoheritage and Geoconservation  
- International case studies and reviews

In this Chapter, the focus of the literature review will be on countries that have long standing policies and legislation for the identification and protection of sites of Geoheritage significance. Particular attention will be paid to where policies for coastal Geoheritage and Geoconservation are developed. To date, largely, environmental policy and legislation have been developed for the purpose of conserving Biodiversity and to a lesser extent Nature. In some instances, legislation has been amended to include Heritage (e.g., the Environmental Protection of Biodiversity Act [Cth; 1999]), and thereby including Geoheritage as a component of Natural Heritage. In addition, most countries, including Australia, use the IUCN Protected Areas Categories System (IUCN 2008) for classifying protected areas according to their management objectives. Large sites, such as Yellowstone National Park (USA) would be conserved as a National Park (IUCN Category II), rather than as a Natural Monument or Feature (IUCN Category III). The conservation categories of IUCN (2008) more explicitly include geological and geomorphological features than those of IUCN (1994) (see Brocx 2008). Most countries have some form environmental legislation that includes the capacity for the ad hoc conservation of sites of geoheritage significance.

Literature reviews that relate to the history of geoconservation and/or the body of legislative instruments undertaken by authors such as Gray (2004), Brocx (2008), Wimbledon & Smith-Meyer (2012) largely have focused on those instrumentalities that protect biodiversity but that also include the capacity to conserve sites of geoheritage significance. However, as the Policy component of this Thesis is specifically oriented to developing policy for the identification and protection of Coastal Geoheritage, the literature reviews and case studies will be confined to those countries with dedicated instruments and tools for geoconservation. Case studies on the development of legal and policy instruments will be provided on the United Kingdom which has over 200 years of initiatives in the identification and conservation of sites of geoheritage significance and governance, and more continuously since 1949, and the United States of America which has a long history of geoconservation and longstanding programmes for geoconservation managed by the Bureau of land Management (BLM)(see Brocx 2008).

A review of the databases of the IUGS Geoheritage Task Group (IUGS GTG 2014) and the IUCN ECOLEX (2014 Environmental Law) shows a limited, but growing number of countries that have legislation enacted specifically for the purpose of the protection of geological sites, i.e., as opposed to geoheritage as a component of Natural heritage or landscapes (Table 10.1). The IUCN ECOLEX database, operated jointly by FAO, IUCN and UNEP, is a one that is described as “providing the most comprehensive, global source of information on Environmental Law”. Unless otherwise noted, the information below has been obtained from these two (linked) sources.
Table 10.1 Counties/Nations with Legislation, policy instruments, programmes, and Declarations for the conservation of sites of Geoheritage significance. (Those with National Legislation are notated with **).

<table>
<thead>
<tr>
<th>Country or Continent</th>
<th>Legislation</th>
<th>Objective as it relates to Geoconservation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Africa Egypt</strong></td>
<td>Law No. 102 of 1983 on Natural Protected Areas.</td>
<td>Creation of natural protectorates where spoiling and destroying geological structures is forbidden</td>
</tr>
<tr>
<td><strong>Australia Tasmania</strong></td>
<td>Nature Conservation Act 2002</td>
<td>Provides for the conservation and protection of the fauna, flora and geological diversity of Tasmania</td>
</tr>
<tr>
<td><strong>Victoria</strong></td>
<td>National Parks Regulations 2003</td>
<td>Provides for promoting and the preservation and protection of, among others, features of geological interest in National parks</td>
</tr>
<tr>
<td><strong>Canada</strong></td>
<td>Alberta: Provincial Parks Act (RSA 2000, c.P-35)</td>
<td>Lays down provisions relating to provincial parks including the preservation of geological objects</td>
</tr>
<tr>
<td><strong>France</strong></td>
<td>A series of direct and indirect Law on the conservation of monuments and works of art with historical and artistic interest (1987). Rights of the Memory of the Earth, June 1991 in Digne, France</td>
<td>France has a series of direct and indirect laws dating back to March 30, 1887</td>
</tr>
<tr>
<td><strong>Malaysia</strong></td>
<td>National Parks Act 1980 (No. 226 of 1980)</td>
<td>For the preservation and protection of wildlife and objects of geological, historical and ethnological interest</td>
</tr>
<tr>
<td><strong>Norway</strong></td>
<td>Nature Diversity Act 2009</td>
<td>Relates to the Management of Biological, Geological and Landscape Diversity</td>
</tr>
<tr>
<td><strong>Papua New Guinea</strong></td>
<td>Conservation Areas Act 1978 (Cap 362)</td>
<td>Conservation of sites and areas having particular biological, topographical, geological, historic, scientific or social importance</td>
</tr>
<tr>
<td><strong>Portugal</strong></td>
<td>Regime Juridico da Conservacao da Natureza e da Biodiversidade (Nature Conservation and Biodiversity Act) - Decreto-Lei (DL) n.° 142/2008, de 24 de Julho</td>
<td>Protection for the geological heritage in National Parks</td>
</tr>
<tr>
<td><strong>Poland</strong></td>
<td>“Official orders” and laws on nature conservation, successively enforced in Poland since 1919 The Nature Protection Law 2004, as amended, now in force</td>
<td>Instruments that provide for the forms/structures and principles of geological monument conservation</td>
</tr>
<tr>
<td>Country</td>
<td>Law/Act/Decree</td>
<td>Protection of archaeological and palaeontological heritage</td>
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<td>------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------</td>
</tr>
<tr>
<td>Brazil**</td>
<td>Law 25743/03 (Ley Nacional 25743/03 Proteccion del Patrimonio Arqueologico y Paleontologico)</td>
<td>Protection of archaeological and palaeontological heritage</td>
</tr>
<tr>
<td>Brazil**</td>
<td>Brazil has a number of laws for direct site specific protection</td>
<td>The Brazilian Commission of Geological and Paleobiological Sites (SIGEP, <a href="http://sigep.cpru.gov.br">http://sigep.cpru.gov.br</a>), created in 1997, to enable the assessment, description and publicising the sites of geological heritage</td>
</tr>
<tr>
<td>South Korea**</td>
<td>Special Act on the Preservation of Ecosystem in Island Areas Including Dokdo Island (Act No. 5447 of 1997)</td>
<td>Provides for the conservation of the natural environment of specified islands, including their geographical and geological features</td>
</tr>
<tr>
<td>Russia**</td>
<td>Federal Law No. 33-FZ on protected areas 1995</td>
<td>Regulates management in the sphere of organization, protection and use of protected areas for the purpose of conservation of unique and typical environmental complexes and objects, notable natural formations,</td>
</tr>
<tr>
<td>The United Kingdom England and Wales **</td>
<td>Countryside Rights of Way Act 2000</td>
<td>The Protection of Sites of Special Scientific Interest (SSSI)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>See above</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Defines multiple-use management as the “management of public lands and their various resource values” and specifically states that areas may be set aside for their geological significance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Those policies in Sections 1, 4 and 8 that relate to Geoheritage will be discussed under the Case Study</td>
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</table>
As discussed in Chapter 9, there is inconsistent use and scope in the meaning of Policy and of Planning. Often the word Policy is used in the sense of a Mission Statement, elsewhere as a Guidance Statement, or in the sense of recipe for actions, or Planning, and Planning directives. For example, use of the International Declaration of the Rights of the Memory of the Earth is used as a Guidance Statement (IUCN GTG 2013), and the suite of 15 points used by the Bureau of Land Management in the United States of America (see later) to identify and rationalise selection of sites of geoheritage significance functionally is a policy though it is not referred to as such in the Federal Land Policy and Management Act in America.

The United Kingdom and the United States of America are provided here as case studies in countries that have well established legislative instruments for the identification and protection of sites of geoheritage significance. Legislation in Portugal is provided as an example of recent developments in identifying and protecting sites of Geoheritage significance in Protected Areas. It is beyond the scope of this Thesis to evaluate the Governance framework.

**Policy and Legislation in relationship to Geoheritage and Geoconservation in The United Kingdom**

The United Kingdom has a geological record spanning the Archaean and Proterozoic to Holocene. Therein there are “standard” geological sites, classic sites illustrating geological principles, and a history of geological exploitation, geological controversy, and geoconservation. Many of the building blocks of global stratigraphical geology, such as the Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and stages of the Jurassic were first recognised in the United Kingdom (Brocx 2008; Thomas & Cleal 2012).

With over 200 years of geological enquiry, the United Kingdom has considerably progressed Policy and Legislation and practice in relationship to Geoheritage and Geoconservation (McKirdy 1990; Page 1992a, 1992b; 1994; O’Halloran et al. 1994; Bennett et al. 1996; Bennett & Doyle 1998; Gordon & Barron 2012; Thomas & Cleal 2005). The history of geological investigations and development of Geoheritage and Geoconservation has been described by Gray (2004), Brocx (2008) Burek & Prosser (2008), Prosser (2013), and Brocx & Semeniuk (2015b). A brief summary is presented here as background to the policies and legislation developed to protect and manage sites of geoheritage significance.

The history of geoconservation in the United Kingdom can be described from different perspectives (such as the contributions of individuals and community groups, or in terms of chronology, or the developing relationship of the geosciences to environment and planning) can be found in Brocx (2008) and in the various contributions in Burek & Prosser (2008).

Thomas & Cleal (2005) provide a concise history of geoconservation in the United Kingdom from the evolution of types of geosites, and their associated legislation. Thomas & Cleal (2005) record the early attempts to conserve geological sites from as early as the late 19th century through to the establishment of Conservation Agencies, the Geological Conservation Review (GCR), and the effects of the Countryside and Rights of Way (CRoW) Act. They outline the legal basis for geological conservation, accounting for the different legislation and conservation mechanisms throughout the United Kingdom. Thomas & Cleal (2005) explain that the best geological sites in the United Kingdom are Sites of Special Scientific Interest (SSSI) in Great Britain selected through the Geological Conservation Review and comparable exercises and, in a separate but comparable process, the selection of Areas of Special Scientific Interest (ASSI) in Northern Ireland. Other non-statutory, but nonetheless important sites, are listed through the mechanism of RIGS. Since 1991 there has been separate but comparable legislation in Scotland, but the scientific framework using GCR is the same (Natural Heritage [Scotland] Act 1991).
Brocx & Semeniuk (2015b) describe five phases of the history of geological inquiry in the United Kingdom (identified as Phases I-V) leading to the development of a science-based inventory of Sites of Special Scientific Interest, legislation to protect those sites that have been identified, and the development of nationwide policies and management strategies. Phase I (1700s-1800s) was the era of geological observations leading to scientific inquiry that included exploring the principles of geology, and the collection of fossils, minerals, and rocks. Phase II (mid 1800s – 1970s) was the period marking the early development of inventories, with the identification of Type Sections, Classic Sites that illustrated geological principles, and Internationally Significant Sites. This phase progressed on two fronts: in the recognition of type sections, and classic sites; and in the recognition of regionally important sites such as the Devonian series at Devon. Phase III (1970s - 1990s) saw the recognition and the development of methods and selection criteria for inventory-based classification and conservation, the foundation of government and non-government organisations to carry out the task, the enactment of legislation to give proclaimed sites legal protection, and the involvement of community groups to select, conserve, and manage sites of scientific and/or cultural heritage. Phase IV (mid 1990s-2006) involved the refining of legislation, revision of the classification and site selection, and development of management plans for sites at all levels of "geoheritage significance", i.e., from international to local significance, within a whole-of-government and integrated scientific framework. In addition, geoheritage values were extended to include intrinsic and cultural values. Phase V (2005-present) involved building on the recognition that geodiversity underpins biodiversity, the development of holistic management strategies by linking geodiversity to biodiversity and geodiversity to land-use planning, and the use of geoheritage areas for geotrails and geotourism. While earlier activities linked geodiversity to biodiversity and used geological precepts in planning (Devon Biodiversity Partnership, 1998, 2005; English Nature 1998), Phase V commenced in earnest around 2005; it is still ongoing, and overlaps with the latter stage of Phase IV.

In this history, Geoheritage and Geoconservation involved numerous milestones (after Brocx 2008; Prosser 2013; Brocx & Semeniuk 2015b). The main ones are listed in Table 10.2.
Table 10.2: Important milestones in geoconservation in the United Kingdom

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
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<tbody>
<tr>
<td>1807</td>
<td>The Geological Society of London founded</td>
</tr>
<tr>
<td>1832</td>
<td>First geological survey conducted at Devon;</td>
</tr>
<tr>
<td>1835</td>
<td>The Geological Ordnance Survey founded</td>
</tr>
<tr>
<td>1887</td>
<td>First practical steps by Local Government in geoconservation of a fossil site</td>
</tr>
<tr>
<td>1945</td>
<td>First inventory of sites later to become sites of special scientific interest (SSSI)</td>
</tr>
<tr>
<td>1949</td>
<td>National Parks and Access to the Countryside Act</td>
</tr>
<tr>
<td>1977</td>
<td>Geological Conservation Review established</td>
</tr>
<tr>
<td></td>
<td>The National Scheme for Geological Site Documentation</td>
</tr>
<tr>
<td>1987</td>
<td>The GeoConservation Commission was founded</td>
</tr>
<tr>
<td></td>
<td>The British Institute for Geological Conservation founded</td>
</tr>
<tr>
<td>1990</td>
<td>Publication - <em>Earth Science Conservation in Great Britain - A Strategy</em></td>
</tr>
<tr>
<td>1991</td>
<td>First educational material Earth heritage conservation principles</td>
</tr>
<tr>
<td>1993</td>
<td>First International Conference on Geoconservation</td>
</tr>
<tr>
<td></td>
<td>Guidelines by JNCC for selection of Earth Science SSSI</td>
</tr>
<tr>
<td>1994</td>
<td>First recognition of Regionally Important Geological/Geomorphological Sites (RIGS) in planning policy</td>
</tr>
<tr>
<td>1997</td>
<td>Position Statement from the Joint Nature Conservation Committee (JNCC) on Conserving Fossil Heritage</td>
</tr>
<tr>
<td>2001</td>
<td>CRoW Act (Country Right of Way): - first time land ownership not an impediment to geoconservation</td>
</tr>
<tr>
<td></td>
<td>First World Heritage Site in the British Isles based on geological values</td>
</tr>
<tr>
<td>2003</td>
<td>The concept of Local Geodiversity Action Plans developed</td>
</tr>
<tr>
<td></td>
<td>Geology Trusts formed</td>
</tr>
<tr>
<td></td>
<td>First European Geopark established in the British Isles</td>
</tr>
<tr>
<td>2004</td>
<td>1990 Earth Science Conservation Classification under review</td>
</tr>
<tr>
<td>2006</td>
<td>Earth Science Conservation Classification revised</td>
</tr>
<tr>
<td></td>
<td>Publication of <em>Geological conservation a guide to good practice: working towards Natural England for people, places and nature</em>.</td>
</tr>
</tbody>
</table>

The most significant advances post-1991 in the development of policy and strategies for Geoheritage and Geoconservation were:

1993: Guidelines by JNCC for selection of Earth Science SSSI
1994: RIGS in planning policy were first recognised
1997: Position Statement from JNCC on Conserving Fossil Heritage
2003: The concept of Local Geodiversity Action Plans (LGAP) was developed
2006: Publication of *Geological conservation a guide to good practice: working towards Natural England for people, places and nature*
2009: JNCC - Update on geoconservation work JNCC 09 N01 (JNCC 2009)
In 1993, the Joint Nature Conservation Committee (JNCC) [the public body that advises the UK Government and devolved administrations on UK-wide and international nature conservation] published ‘Guidelines for selection of Earth Science SSSI’. In the definition of what is a ‘policy’ discussed in Chapter 9, these guidelines could be viewed as policies. The purpose of the JNCC document was to summarise guidelines for the survey, evaluation and selection of Earth Science SSSI. This is a process known as the Geological Conservation Review (GCR) whereby the country councils throughout the United Kingdom had a mechanism to identify important sites and then discharge their statutory duties (under the Wildlife and Countryside Act 1981, Environmental Protection Act 1990 and the Natural Heritage [Scotland] Act 1991) to notify any area of land which in their opinion is of special interest by reason of its Earth Science (geological and physiographic) interest. The objective of the Earth Science SSSI system is to identify and conserve a series of Sites of Special Scientific Interest for their ‘geology and physiography’ across the whole of the United Kingdom. Each site within the series must have a special interest demonstrable at national or international level, either in its own right or by virtue of its contribution to a network of closely related sites. The special interest of the series is interpreted as the minimum number of sites needed to demonstrate current understanding of the diversity and range of Earth Science features with regard to selected criteria or selected themes. The guidelines also provided a rationale by setting out the objectives, general principles and philosophy of the GCR, and outlined the criteria used in the evaluation and selection of GCR sites. In developing the guidelines, the JNCC provided the following seven criteria for selection of Earth Science SSSI (JNCC 1993): 1. the concept of ‘minimum number’ of sites; 2. the concept of ‘current understanding’; 3. representativeness; 4. exceptional features; 5. International importance; 6. complete GCR coverage; and 7. operational criteria and preferential weightings. The justification for Earth Science conservation was rationalised previously by the Nature Conservancy Council (1991), the values of Earth Science sites being founded in their potential for Scientific research, Education, training, economic use, leisure, and aesthetic purposes.

Regionally Important Geological/Geomorphological Sites (RIGS) is a programme that was initiated in 1990 by the National Conservancy Council to create a national network of locally conserved sites (Nature Conservancy Council 1991; JNCC 1993; Collinge & Prosser 1994). RIGS groups (comprised of voluntary members that combine the expertise of local wildlife trusts, museums and geological societies, with the needs of teachers, planners and site owners) select and manage sites. RIGS are selected for their value to Earth Science, in terms of their scientific, educational, historic, cultural, and aesthetic aspects, and to Earth Heritage in general. Though not nationally protected by legislation, RIGS are conserved and protected from development through the local planning system by the Town and Country Planning Act 1990. In 1994, planning policies for the first time formally recognised these Regionally Important Geological/ Geomorphological Sites.

Conservation of Fossil Heritage was recognised in a position statement by the Joint Nature Conservation Committee (1997) - though called a 'position statement', it essentially has the elements of a 'policy'. The focus on conservation of Fossil Heritage was an important step in geoconservation because the principles outlined in this position statement could equally be applied to other significant sites that manifest various other aspects of geology (e.g., mineral localities, important lithologies, and speleothems, amongst others. For Fossil Heritage, the position statement recognised a particular component of Geology, and the special procedures and management required for fossil sites. For instance, it provided guidelines on the collection from and preservation of fossil sites, and a Code of Good Practice in relation to access, site management, collecting, and recording and curating.

A fairly comprehensive treatment of the coastal geomorphology of Great Britain was provided by May & Hansom (2003) wherein they summarised the results of the site evaluation and selection programme of the coastal regions of Britain undertaken between 1980 and 1990 as part of the Geological Conservation Review (GCR). They presented highlights of 99 sites of coastal geomorphology in
Britain, selected eventually for part of the GCR to be considered for long-term conservation under British Law. In this work, May & Hansom (2003) considered the coastal marine environment of tides, waves, surges and currents, coastal sediment supply and sediment cells, sea level history, patterns of geological outcrops along the coast in having a fundamental control on the nature of the coastline, the general order of resistance to erosion of rock types, coastal topography as a result of underlying geology, controls on coastal geomorphology by inter-fluve level, the geological influence on sediment supply into coastal systems, and coastal management and coastal engineering. The list of GCR sites was used as a basis for establishing Earth science Sites of Special Scientific Interest (SSSI), protected under the Wildlife and Countryside Act 1981 (May & Hansom 2003).

Planning Policy Statement 9 (2005), replaced in 2012 by the National Planning Policy Framework, sets out planning policies on protection of biodiversity and on geological conservation through the planning system. This replaced Planning Policy Guidance 9: Nature Conservation published earlier in 1994. Planning Policy Statement 9 stated that regional planning bodies should liaise with the British Geological Survey and, where appropriate, with local RIGS groups on geodiversity issues. Where they have been produced, it was recommended that good practice would use Local Geodiversity Action Plans (LGAPs) as a framework upon which to audit, conserve, manage and promote characteristic geological, geomorphological and soils resources within a particular region or local authority area. LGAPs integrate conservation action between national and local conservation designations and their surrounding geological context. Production and implementation of plans involve a wide range of local groups, organisations and individuals in agreeing priorities and actions for the conservation and promotion of the geodiversity of an area.

To ensure that Regional Spatial Strategies deliver the objectives set out in Planning Policy Statement 9 in relation to geoconservation, Regional Planning Bodies were recommended to adopt key aspects of good practice: 1. integration of all other regional strategies with a bearing on regional geological conservation; 2. developing a comprehensive information base on regional geological resources; 3. ensuring that geological objectives are embraced within a broader regional vision supported by a spatial strategy and appropriate policies; 4. including geological conservation within a clear implementation strategy measured by appropriate targets and indicators; 5. developing sub-regional strategies which address the protection and enhancement of geological conservation and applying this to growth areas.

In 2005, Circular 06/05: Biodiversity and Geographical Conservation - Statutory Obligations and Their Impact within the Planning System (ODPM 2005) provided administrative guidance on application of the law in England relating to planning and nature conservation. This guide complements those publications and provides good practice guidance on ways regional planning bodies and local planning authorities can help deliver the national policies in Planning Policy Statement 9 and comply with legal requirements set out in the Circular.

In Scotland, Gordon & Barron (2012) discuss the values and benefits of integrating geodiversity and geoconservation into environmental policy and developing a more strategic ecosystem approach for Scotland’s National Performance Framework and Strategic Objectives. The values/benefits are related to economic development, climate change adaptation, biodiversity, Science and Education, and recreation, health and cultural inspiration. Gordon & Barron (2012) suggest that integrating geodiversity into relevant policies and decision frameworks would provide a more strategic, ecosystem-based approach to address future-proofing of ecosystem services (particularly in regard to climate change and rising sea-levels), conservation and sustainable management of geodiversity (in designated sites and in the wider region), raise awareness of the value of geodiversity and its contribution to ecosystem services, and improve understanding of geodiversity and key knowledge gaps. Such an approach has been adopted in the Scotland’s Geodiversity Charter (Scottish
In their paper Gordon & Barron (2012) directly interface the benefits of conserving and managing geodiversity with ecosystem services and highlight the importance of geoconservation. This philosophy, while emphasising geodiversity in its relationship to biodiversity and ecosystem services, and conserving areas of certain types of geodiversity, actually does not address the matter of Geology (sensu stricto) or that of geoheritage. In this context, for instance, areas such as the geologically important sites of Siccar Point strictly would not be captured as sites of geoconservation/geoheritage significance.

Scotland has also focused on coastal and marine geoheritage. Legislation was introduced through the Marine (Scotland) Act 2010 and the Marine and Coastal Access Act 2009 to enable establishment of Nature Conservation Marine Protected Areas (MPAs) within Scottish territorial and offshore waters. Guidelines for the selection of MPAs in waters adjacent to Scotland have been drafted by Marine Scotland, Scottish Natural Heritage and the Joint Nature Conservation Committee. These guidelines highlighted the need to identify the key biodiversity and geodiversity areas in Scottish waters through a robust scientific framework with supporting justification. In this regard, Brooks et al. (2011) focused on identification of key geodiversity areas in Scottish marine and coastal waters. Brooks et al. (2011) outlined a methodology (based on the Geological Conservation Review [GCR] scientific framework for the identification and prioritisation of important aspects of Earth Heritage in the terrestrial environment, as mentioned above) to prioritise key geodiversity areas in Scottish waters. Amendments to the existing GCR methods were introduced in order to ensure consistency with the Scottish MPA selection guidelines. These guidelines prioritise areas that contain key features considered of national or international importance, that contain features considered to be under threat and/or subject to rapid decline, and/or that are of functional significance for the overall health and diversity of Scottish Seas. Brooks et al. (2011) provide details of the key geodiversity areas identified in Scottish waters. The list of key geodiversity areas was compiled using the GCR-style scientific framework and based on expert judgment and the recommendations from a workshop attended by a range of leading Earth scientists with expertise in the Scottish marine environment. Brooks et al. (2011) then identified key geodiversity areas and delineated their boundaries.

The more detailed aspects of the criteria and the bases for criteria for selecting sites of geological significance in the United Kingdom, and how comparative site assessment was carried out, drawn from Thomas & Cleal (2005) are provided below as this will have bearing on design of policy for coastal geoconservation.

Earth Scientists and Geoheritage Practitioners in the United Kingdom have determined that to assess the relative importance of sites, it was essential that each site should be based on a system of comparing 'like with like' (Thomas & Cleal 2005). Thomas & Cleal (2005) point out that it is not possible to assess objectively the relative merits of, say, a Jurassic stratigraphical site and a Palaeozoic igneous site, and so some form of comparative system needs to be established. The GCR was, therefore, based around a hundred 'Selection Blocks' that effectively divided the geology and geomorphology of the United Kingdom into meaningful units of time, geography and type of rock formation. For the United Kingdom, after literature review, consultations, field assessments, and revisions of draft lists, a distilled list was constructed based on the criteria shown in Table 10.3 (Thomas & Cleal 2005):
Table 10.3: Criteria for selection of sites for the Geological Conservation Review
(to assess international importance; exceptional features; representativeness; Ellis 2011)

1. was the site conservable?
2. was site's interest shown better at another British site?
3. did the site show one feature or an assemblage of related features?
4. did the site have extended and complete record of the feature it was showing?
5. was the site representative for the feature it was supposed to be showing, or did it give an atypical and therefore misleading impression of the feature?
6. had the site been extensively studied?
7. did the site have potential for future study (palaeontological or mineralogical sites that were 'worked out' were not normally considered)?
8. did the site yield superlative results?
9. was the site in a significant palaeogeographical position, which, for instance, yielded data linking 'core areas' or demonstrated facies changes?
10. what was the contribution of the site to our overall understanding of the sites in the Selection Block?

After this type of assessment and further consultation with the relevant specialists, a list of 3,081 GCR Sites was produced for Great Britain representing the best sites (or in some cases the only site) for the key geological and geomorphological feature. The strengths of these GCR lists were threefold: 1. they were developed exclusively through a comparative analysis of the scientific content of each site; 2. each site is judged to be of at least national significance; and 3. the assessment was made in collaboration with the wider geological community. The GCR Sites became the basis for a new set of Earth Science SSSI that form the foundation of present-day geoconservation in Britain (Allen et al. 1989).

Geoconservation outside of the GCR initially centred on concerns about the pre-GCR SSSI that had not come up to the standard of a GCR, and were due to be de-scheduled. It was also realised that there were sites that, although not of national importance in a scientific sense, fulfilled an important local role for education, recreation, and/or geotourism. This led to the concept of the Regionally Important Geological Sites (RIGS). As RIGS are intended to serve local needs, the criteria used to select them tended to be locally developed. This suggested that RIGS should be selected according to their value for:

1. educational fieldwork in schools, colleges and universities;
2. scientific study by both professional and amateur Earth Scientists;
3. understanding the historical development of Earth Sciences;
4. aesthetic qualities, particularly in relationship to promoting public awareness and appreciation of the Earth Sciences.

The Geological Reserves Subcommittee incorporated these suggestions into their revised classification of Geological Reserves (Chubb 1945), with four categories being defined (Table 10.4):
Table 10.4: Classification of Geological Reserves (Geological Reserves Subcommittee)

1. Conservation Areas (geological): large-scale physiographic features and areas containing many items of geological interest, to be treated as Conservation Areas. Working quarries in such areas were to be registered [see under category (4) below]; new quarries or other works to be undertaken only after approval had been obtained from an appropriate authority advised by a scientific panel.

2. Geological Monuments: small-scale geological features and sections of outstanding interest, to be permanently protected and kept in a good state of preservation.

3. Controlled Sections: natural sections and artificial sections in a state of disuse, to be subject to control on account of their scientific value, in order to prevent them being irretrievably obscured by building or dumping of refuse, or otherwise rendered inaccessible.

4. Registered sections: sections of exceptional geological importance at present used or worked, to be listed and to be kept under observation by an appointed authority, the owners or lessees being required to give notice to it of their intention to cease operations, in which event the sections in question would be considered for transference to the previous category (3).

As a consequence, the United Kingdom has a range of sites of geoheritage significance varying in their size and scope of features (from geoparks to World Heritage sites to local geosites), in their nomenclature, in their statutory to legislative management, and in their range of designations as significant internationally, nationally and locally. These are listed in Table 10.5 below. These categories of sites and level of geoheritage significance provide a description and a model of how geoheritage is dealt with in the United Kingdom.

Table 10.5: Current categories, levels of significance, and protection for sites of geoheritage significance in the United Kingdom

<table>
<thead>
<tr>
<th>INTERNATIONAL LEVEL OF SIGNIFICANCE &amp; SITE DESIGNATION</th>
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<tbody>
<tr>
<td>At the international level in the United Kingdom, there are World Heritage sites, Geoparks (UNESCO designation based on outstanding geodiversity and its successful use as a tourist attraction), Ramsar sites, and some sites within National Parks, as well as some SSSI</td>
</tr>
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<thead>
<tr>
<th>NATIONAL LEVEL OF SIGNIFICANCE &amp; SITE DESIGNATION</th>
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<tbody>
<tr>
<td>National Parks have Geological Conservation Review (GCR) site status; some, but not all, of these GCR sites are protected by Site of Special Scientific Interest (SSSI) legislation; the remainder are protected by policies for GCR site protection that exist in the Local Plans for both National Parks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LOCAL LEVEL OF SIGNIFICANCE &amp; SITE DESIGNATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Nature Reserves (NNR) contain significant sites of geological and geomorphological interest, with many NNR area also having GCR site status</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sites of Special Scientific Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sites of Special Scientific Interest (SSSI) are the primary statutory mechanism for geodiversity protection in the United Kingdom; the Geological Conservation Review (GCR) underpins designation of geological SSSI</td>
</tr>
</tbody>
</table>

| The Marine and Coastal Access Act 2009 and the Marine (Scotland) Act 2010 allows for conserving of geological or geomorphological features in Marine Protected Areas (MPAs) as part of Marine Nature Conservation in territorial waters adjacent to England, Wales, and Scotland |

<table>
<thead>
<tr>
<th>LOCAL LEVEL OF SIGNIFICANCE &amp; SITE DESIGNATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local Nature Conservation Sites include Local Geodiversity Sites (LGS), and are also termed 'Regionally Important Geological and Geomorphological Sites' (RIGS).</td>
</tr>
</tbody>
</table>
In terms of legislation, Thomas & Cleal (2005) point out that Nature conservation in the United Kingdom, depending on site, is founded on international treaties and conventions to which the United Kingdom is a signatory, and on domestic legislation. However, there is no overall legislation, nor single set of regulations for geological conservation that covers the whole of the United Kingdom. In this context, conservation has to take account of the different legislation and mechanisms for geological conservation throughout the United Kingdom. The international initiatives such as World Heritage Sites, Geoparks and Global Geosites, Global Indicative List of Geological Sites (GILGES) and Global Boundary Stratotype Section and Points (GSSP) are also part of the geoconservation endeavour in the United Kingdom, and legislation has to involve international legal mechanisms.

In terms of protection of geoheritage sites, the following information is relevant: 1. for sites of International level of significance, geoparks are not statutory designations and have no protection; individual geosites within geoparks may be protected as SSSI or informally as LGS/RIGS; Ramsar designation does not protect geoheritage interests, although some may coincide spatially with some geosites; and 2. for sites of National level of significance, National Parks in themselves do not protect geosites, but may protect them through Park plan policies, and though they do not have GCR status they may contain GCR sites and SSSI.

**Policy and Legislation in relationship to Geoheritage and Geoconservation in the United States of America**

The United States of America globally has some of the largest areas in the conservation estate and has the earliest legislative mechanisms for conservation of ‘national monuments’, beginning with the Antiquities Act 1906 (Brocx 2008). The Act declares (Alberwerth 2002): “The President of the United States is authorised in his discretion to declare by public proclamation historic landmarks, historic and prehistoric structures, and other objects of historic or scientific interest ... compatible with proper care and management of the objects to be protected”.

Between 1906 and 2014, sixteen United States Presidents have used this Act to proclaim 178 National Monuments ranging in size from 0.004 sq km to ~ 9 million sq km (Misty Fjords, east of Ketchikan, Alaska by President Jimmy Carter; Wilderness Society 2015). Currently, in addition to Presidential Proclamations made under the Antiquities Act, the conservation and management of National Monuments and National Conservation Areas is directed by a variety of Federal laws and regulations under the Bureau of Land Management's newly created National Landscape Conservation System (Wilderness Society 2002). These include the Federal Land Policy Act 1996 and the National Environmental Policy Act of 1969. In 1998, the United States Bureau of Land Management (BLM) issued a statement that defines the important aspects of geological heritage and also the anthropogenic and natural threats to this heritage as part of a National Strategy to Implement a Geological Heritage Initiative. The intent of the initiative was to encourage recognition, interpretation, education, research and consistent management of geologically significant sites in accordance with natural resources management provisions of Section 102 of Federal Land Policy and Management Act. Significant geological phenomena identified for conservation are managed as a part of the National Landscape Conservation System National Monuments Programme under a 15 point Statement as shown in Table 10.6 (after Weighwell & Torfason 2002):
Table 10.6: The 15-point Statement for site selection in United States of America

<table>
<thead>
<tr>
<th>No.</th>
<th>Type of Site</th>
</tr>
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<tbody>
<tr>
<td>1.</td>
<td>the place where a geologic feature, rock type, type specimen of a plant or fossil was first recognised and described (i.e., type localities).</td>
</tr>
<tr>
<td>2.</td>
<td>historically significant sites where original contributions to the understanding of geologic processes or principles were inspired.</td>
</tr>
<tr>
<td>3.</td>
<td>textbook examples of geological features and processes.</td>
</tr>
<tr>
<td>4.</td>
<td>palaeontological localities and other sites that contain scientifically significant stages of biological evolution in the fossil record.</td>
</tr>
<tr>
<td>5.</td>
<td>features created by wind, water, ice, weathering and mass wasting.</td>
</tr>
<tr>
<td>6.</td>
<td>caves and karst topography.</td>
</tr>
<tr>
<td>7.</td>
<td>hot springs, artesian springs and aquifers.</td>
</tr>
<tr>
<td>8.</td>
<td>geologic features that offer classic research or educational opportunities.</td>
</tr>
<tr>
<td>9.</td>
<td>outstanding examples of significant stages in the Earth’s evolutionary history.</td>
</tr>
<tr>
<td>10.</td>
<td>variety of related and significant geologic features within a small geographic area; even though any one feature may not be worthy of special recognition, the combination of related features in proximity may be unique and geologically significant.</td>
</tr>
<tr>
<td>11.</td>
<td>mines and mining districts that have geological or historical significance.</td>
</tr>
<tr>
<td>12.</td>
<td>geological curiosities such as meteorites, non-volcanic craters etc.</td>
</tr>
<tr>
<td>13.</td>
<td>unique or uncommon rock or mineral sites.</td>
</tr>
<tr>
<td>14.</td>
<td>geological features, formations and landscapes that have exceptional natural beauty, with existing or potential recreational uses.</td>
</tr>
<tr>
<td>15.</td>
<td>rock and mineral specimen collection sites with intense recreational use or widespread educational value, or the potential for such recreational or educational use.</td>
</tr>
</tbody>
</table>

While strictly the 15 point Statement provides rationale as to why sites should be selected for conservation of geoheritage features, effectively it functions as a policy statement.

The National Landscape System in the United States of America was established in 2000 under the auspices of the Bureau of Land Management. Its role is to help protect some of the nation’s most remarkable and rugged landscapes. It manages ~107 million hectares) of public lands, including 15 new National Monuments and 14 National Conservation areas, Wild and Scenic Rivers, and National Trails (BLM 2002a, b). Geoconservation in the United States of America has been identified as important for a variety of reasons as shown in the list in Table 10.7.

Table 10.7: Rationale for geoconservation in the United States of America (BLM 2002a, b)

- because of a commitment to preserving our Earth heritage for the future;
- the principle of sustainability;
- to allow research for the advancement of science and for the success of industry;
- to train Earth scientists;
- to provide an essential teaching facility for schools;
- as a focus for substantial leisure activities and tourism (collecting, walking, etc.);
- monitoring environmental change;
- because important geological and geomorphological sites have aesthetic, amenity, historical, cultural and wildlife value;
- because the geological and geomorphological elements in our landscapes underpin biological and human diversity.
The United States of America provides two models of how geoconservation unfolded: that of an early stage which is similar to modern Australia where resource exploitation was pursued above all other values, and that of a latter stage in which geoheritage was progressively being considered as part of land policy and land management. While the United States of America has not been part of Geosites or ProGEO programmes, it has nonetheless developed its own philosophy, programmes, and priorities for geoconservation. The National Landscape Conservation System National Monuments Programme with its 15 point Statement parallels and overlaps many of the key points crystallised elsewhere globally. In this matter, the United States of America, through its National Landscape Conservation System National Monuments Programme, provides similar and collaborative guidelines for geoconservation and selection of sites of geoheritage significance.

The United States of America thus provides a good model for the rationale for geoconservation, the criteria for selection of sites for geoheritage/geoconservation, and some of the policies and guidance.

Policy and Legislation in relation to Geoheritage/Geoconservation in Portugal

While Nature conservation in Portugal is dominated by conservation of biology, biodiversity, and ecosystems (Brilha 2002), sites of geoheritage significance and geoconservation, however, the Regime Juridico da Conservacao da Natureza e da Biodiversidade (Nature Conservation and Biodiversity Act) - Decreto-Lei (DL) n. 142/2008, de 24 de Julho, legislates for direct protection for the geological heritage in National Parks, Natural Parks, Natural Reserves, Protected Landscapes, and Natural Monuments (Brilha 2012). At the international level, there also are two Geoparks (Arouca Geopark, and the Azores Geopark) and a three sites on the tentative World Heritage list that have geological significance (Algar do Corvao, a strombolian volcano, the Southwest Coast, and Jurassic dinosaur track-ways o Jurassic age viz., the Galinha and Vale de Meios tracksites, and the Pedra da Mua tracksite; cf. Santos et al. 2009).

Portugal has a national geosite inventory, and is one of the few nations that have legislation to protect sites of geoheritage significance. In 2004, a Decree was issued that would protect registered sites of geoheritage significance on Madeira (Diário da República 2004). This Decree defined the objectives for the conservation and protection of geological heritage on Madeira (an archipelago of Portugal). Among its objectives were: 1. promoting a conservation and protection policy for geological heritage; 2. identifying, classifying, registering, documenting and disseminating information on sites of geological interest; 3. promoting/providing knowledge of geological heritage through research, study and training and teaching; 4. promoting community awareness on the importance and relevance of geological heritage; 5. defining intervention areas and implementing strategies; and 6. promoting the defense (protection) of natural resources in accord with development of economic activities.

Since 2004, the legislation once centred on Madeira has become more national and, accordingly, Portugal now has legislation that protects all its geoheritage sites (or geosites) that lie within protected areas. Brilha (2010) discusses the present linkage between nature conservation, legislation, geological heritage, and geoconservation, and describes the current status of Portuguese legislation that can be used for geosite protection. In discussing the newly emergent legislation enacted in 2008, Brilha (2010) stresses there is now integration of geological heritage for the first time in Portugal. There is, therefore, a legal framework related to Nature conservation and land-use planning, similar in principle to instrument structures, and mechanisms to that which exist for sites of geoheritage significance in the United Kingdom.

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Discussion
There are principles from international and national policies described above that can be used in developing policy for protecting sites of significance in coastal geoheritage in Western Australia (see later).

The development of protocols, strategies, policies, and legislation for geoheritage and geoconservation throughout the World, axiomatically, has largely been iterative and evolutionary, and without an initial strategy. It has been through the work of geologists, associations, and organisations such as ProGEO and the IUGS that have progressed the geoconservation movement through research and knowledge acquisition, land-use conflicts, consciousness-raising, insights and epiphany. Only after knowledge has been accumulated can sites of geoheritage significance be appreciated, and only after knowledge has been accumulated around the World could local sites be appreciated in either a global or a regional comparative context.

The United Kingdom and its geoconservation endeavours stands as a historical model of how acquisition of geological knowledge and appreciation of the need to protect sites that formed the basis for that geological knowledge led to development of policies and legislation for geoconservation of sites of geoheritage significance. Nations that are still at the beginning or yet to begin Phase II (the development of inventories, with the identification of Type Sections, Classic Sites that illustrate geological principles, and Internationally Significant Sites) can then move purposefully to Phase III (by implementing methods and selection criteria for inventory-based classification and conservation, establishing government and non-government organisations to carry out the task, enacting legislation to give proclaimed sites legal protection, and involving community groups to select, conserve, and manage sites of scientific and/or cultural heritage), and then to Phase IV by refining legislation, revising classification and site selections, and developing management plans for sites of geoheritage significance, with a whole-of-government and integrated scientific framework. Next, Phase V could be implemented by integrating and linking geodiversity to biodiversity and geodiversity to land-use planning, and using of geoheritage areas for geotrails.

The work by May & Hansom (2003) on the coastal geomorphology of Great Britain, while comprehensive and very applicable to Great Britain, is largely focused coastal geomorphology. Aspects of the work that have some relevance to the Western Australian coast are the issues of rock erosion, types of vulnerable coasts, and the pattern of geological outcrops that control the nature of coastlines, but for the most part only the principles of coastal management and site selection are relevant because the coast of Great Britain is very different to that of Western Australia.

The other lessons from the United Kingdom are the multi-layered structure of policies and legislation and management with the variable policies and legislation that address the amount of detail required at local level versus at the national level. Therefore, using the United Kingdom model, sites of geoheritage significance can be allocated to World Heritage sites, Nationally significant site, SSSI, and RGIS, with appropriately designated authorities to manage the sites (such as JNNC, NCC, or local authorities), and appropriate legislation to manage and protect the sites.

One of the useful methods deriving from the United Kingdom was the set of criteria to determine the importance of sites that were presented in Table 10.3. The criteria of Table 10.3, with some modifications, can be directly applied to the Australian situation and to allocating relative importance to sites and to geosites in coastal geoheritage. Specifically, after a list of geoheritage sites is established in coastal Western Australia (similar to what was pursued to refine the GCR lists), in order to prioritise what may be a list involving (potentially) hundreds of geosites, the criteria of Table 10.3 can be applied. This will provide, firstly, a comparative analysis of the scientific content of the
various geosites/geoparks, secondly, an assessment that each site is at least nationally significant, and thirdly, an assessment of geoheritage values in collaboration with the wider geological community. The criteria in Table 10.3, while globally applicable, can be used in Western Australia to select a diversity of sites of geoheritage significance and be part of the Geoheritage Tool-kit Step 2 (Figure 7.1).

The criteria used for selection of RIGS also are useful where the rationale for site selection and site value is required based on usefulness for educational fieldwork for schools, colleges and universities, scientific study by professional and amateur Earth Scientists, understanding the historical development of Earth Sciences, and aesthetic qualities, particularly in relationship to promoting public awareness and appreciation of the Earth Sciences. As with those in Table 10.3, these criteria can be used in Western Australia in the application of the Geoheritage Tool-kit at Step 2 to select and rationalise sites (Figure 7.1).

In Australia Federally, and in Western Australia, as yet, there is no framework for systematic science-based inventories of geological sites nation-wide or State-wide (respectively) so that, in this regard, Australia and Western Australia are not yet at Phase II in the historical unfolding of geoconservation that the United Kingdom has presented. As such, while many of the organisations, programmes and outcomes in the United Kingdom are worthwhile (RIGS, SSSI, JNCC, NCC), geoheritage and geoconservation endeavours in Australia federally and in Western Australia cannot proceed using the United Kingdom as a model because they have not even developed a level of geological information equivalent to Phase II in the history of geoconservation as presented by the United Kingdom. So while the United Kingdom has developed policies and legislation as an outcome of its history with respect to geology and its people; Australia and Western Australia have neither the history of geological enquiry nor the scientific/geological ethos – they are still in their exploitation stage. Interestingly, South Australia, with its extensive documentation of geosites on its database, is well within the Phase II of its ‘geoconservation development’.

In terms of policies and plans, in the United Kingdom national policies and plans are too generalised and not site-specific enough to be of use at the local scale in Australia (the scale at which significant geological features are commonly manifest). Further, the importance of many sites has been known for a long time since the United Kingdom has a long history of geological enquiry and a long list of sites of internationally and nationally important locations and classic sites and so it is at the RIGS and LGAPs scale where local knowledge and experience is available that the best practice and outcome for geoconservation has been achieved. In this context, translating this to the importing of ideas to Australia, the generalised national policies of the United Kingdom can only be used to broadly indicate concepts, i.e., they will be generalised statements that cannot be applied to site-specific situations. At the other extreme, the RIGS and LGAPs level is too specific to the United Kingdom geology to be applicable to Australian and Western Australian geological situations. However, as previously stated, the principles of RIGS and LGAPs are applicable at the local scale in Australia and Western Australia, but not the details of geology and the specific policy, education brochures, education signage, and management required for RIGS and LGAPs. Thus RIGS and LGAPs illustrate local knowledge applicability, while Planning Policy Statement 9 (and its replacement Policy) was/is nation-wide in scope and hence generic. As such, the principles of national geoconservation and the principles of SSSI and RIGS and LGAPs are applicable to Western Australia but the details of the United Kingdom experience are not.
However, as noted above, the selection criteria of RIGS and the approach, criteria and process of the GCR can be successfully applied to Australia and Western Australia. Similar to the United Kingdom, there can be in Australia and in Western Australia sites that, although not of national importance in a scientific sense, fulfill a local role for education, recreation, and/or geotourism in that they are useful for educational fieldwork in schools, colleges and universities, scientific study by both professional and amateur Earth Scientists, understanding the historical development of Earth Sciences, and aesthetic qualities, particularly in relationship to promoting public awareness and appreciation of the Earth Sciences.

Coastal geoheritage and its importance as identified in this Thesis and by Brocx & Semeniuk (2009a) generally is not specifically addressed globally or in the United Kingdom in the scope and detail it is here, though the importance of coastal outcrops is recognised in the United Kingdom in that coastal exposures provide excellent exposures with clean outcrops (Brampton 1998, Leafe 1998). Hence there are policies or guidelines designed for sites of geoheritage significance in the coastal zone but these, however, are focused on well-exposed geosites in coastal zones rather than a focus on ‘coastal geoheritage’. Accordingly, there are no relevant policy developments in this arena of coastal Geoheritage to draw upon.

The conservation of Fossil Heritage in the United Kingdom (JNCC 1997) is another example of application of principles. The matter of conservation of Fossil Heritage as practiced in the United Kingdom is directly relevant to the Australian and Western Australian setting but, for coastal geoheritage, the principles if not the details of conservation of fossil sites is of relevance.

In an overview, while the JNCC provides a framework that recognises Geoheritage as a matter for conservation, there are no national policies in the United Kingdom, with regards to Geoheritage sites, geoconservation, or management - rather there are NGOs, LGAPS, and manuals for planning and management. While there might be site-specific manuals of how to preserve and manage geosites if they were important, these are developed by local Shires with the help of geological expertise. This is axiomatic in hindsight because geology and type of exposure and importance of site will be different from region to region and hence the various local governments will need policies (or objectives) and methods tailored for their region. For instance, the following factors will result in different expressions of the geology of an area and degrees of importance of a site and the type of management required for the site: the regional geological setting with its structural style and lithological suite; the quality of outcrop; type of outcrop geomorphically (sea cliff versus river bank cliff versus hill-side, amongst other types of outcrop).

In summary, the geology of the United Kingdom is well known and geosites have been documented nation-wide and, as a result, geoheritage and geoconservation can go to the stage of GCR, RIGS and LGAPs as it has the framework and community interest (due to the high population) to be at this stage. This is not the case for Western Australia. However, in terms of principles and procedures, GCR and RIGS can be used at Step 2 of the Geoheritage Tool-kit (Figure 7.1).

The United States of America provides an alternative model, useful for the rationale for geoconservation, the criteria for selection of sites for geoheritage/geoconservation, and some policies and guidance. The United States of America provides two models of how geoconservation unfolded: that of an early stage which is similar to modern Australia where resource exploitation was pursued above all other values, and that of a latter stage in which geoheritage was progressively being considered as part of land policy and land management. In developing geoconservation, the United States of America provides a set of reasons as to why geoconservation is important as presented in Table 10.6, and further, provides a rationale for the selection of sites for the conservation of
geoheritage features as shown in Table 10.7. The information in both Tables is globally applicable, and can be used in Western Australia to select a diversity of sites of geoheritage significance. In terms of the Geoheritage Tool-kit, it can be used at Step 2 (Figure 7.1).

Portugal also provides a global model of how geoconservation should proceed, with its strategy for conservation and protection policies for geological heritage, beginning with identification and classification of sites, to the promotion of knowledge through research, study and training, teaching, and community awareness to the protection of natural resources in accord with development of economic activities.

Given that globally coastal geoheritage has not been identified as a heritage endeavour, there has been no development of policies and legislation to address what needs to be conserved, what details are required in procedure to protect coastal sites, and what details are required in procedure to protect people from the natural hazards of the coastal zone. As such, development of policy and legislation in this arena for Western Australia is an entirely new field of endeavour and will be the subject matter of Chapters 12 & 13.
Chapter 11: Policy and Legislation in relationship to Geoheritage and Geoconservation - Australian case studies and reviews

This Chapter presents a brief historic review of Government and non-government agencies, instrumentalities and tools that have been formulated Federally and in those States and Territories where Geoheritage and Geoconservation is recognised.

There are three levels of government that manage natural resources, *i.e.*, National, State/ Territory, and Local. Only the main instruments and bodies that deal/dealt with heritage and geoconservation at the Federal and State/Territory level, at the level of two Government Agencies (*i.e.*, Federal and State) will be reviewed in this Thesis. At the National level, this Chapter will provide/describe:

1. Introduction to the current Federal framework dealing with Geoheritage and Environmental matters- the Australian Constitution, and COAG;
2. The Department of Environment;
3. Achievements and deconstruction of the now-extinguished Australian Heritage Act (1975), *i.e.*, the era of the Australian Heritage Commission;
4. The Regional Forests Agreement (RFA) under the Department of Agriculture and Australian Nature Conservation Agency, and its incorporation in the EPBC Act;
5. The Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and amendments;
7. The present era of the Department of the Environment; and
8. The Geological Society of Australia Inc. (GSA),

At the State/Territory level, this Chapter will describe relevant geoheritage and geoconservation endeavours in Tasmania, Victoria, South Australia, and New South Wales and whether they hold scope for how Geoheritage and Geoconservation might be better addressed in Western Australia. At the State level, The National Trust (WA) and the Heritage Council (WA) also provide scope for how Geoheritage and Geoconservation could be addressed. In Western Australia, out of the array of environmental policies and legislation that may have relevance to Geoheritage and Geoconservation, the Department for the Protection of Wildlife (DPaW) Western Australian Wetland Policy (Anon 1997) is examined because it is an approach founded on geomorphic and hydrologic principles. The Western Australian Government has addressed these hydrogeological aspects in the protection and conservation of wetlands beyond just their biological aspects.

As in the International reviews, while principles underpinning policy and legislation in Geoheritage and Geoconservation are reviewed and described in a general manner for the regions/States mentioned above, there will be later a focus specifically on how such policy and legislation have been developed for the coastal zone.
Introduction to the current Federal framework dealing with Geoheritage and Environmental matters

The Commonwealth of Australia Constitution Act 1900 established the Australian Federation, and provided the legal framework by which Australia is governed. It established limits to the powers of the Federal Government and those of the States and Territories. But there are some important aspects of government, such as the environment, that are not mentioned in the Constitution at all (Maddox 2000). However, in 1983, in Commonwealth v Tasmania (1983) 158 CLR 1 (commonly referred to as the Gordon below Franklin Dam Case; reviewed in Brocx 2008), the High Court of Australia established that under section 51(xxiv) of the Constitution, the Australian Government has the power to enact legislation that enables Australia to fulfill its international legal obligations (in this case, World Heritage Listing). Since that time, the Federal government has relied on its Constitutional powers under section 51(xxiv) over external affairs, trade and commerce, and corporations, to pass laws relating to environmental matters, and enacted Australia’s central environmental law, the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

Therefore, whenever the Australian government enters into international agreements, under the Constitution the Commonwealth has the power to enact legislation to enable Australia to conform to meeting the Treaty or Convention objectives. Once this has been established, as a Federation, the States and Territories are bound to enter into interlocking Legislative policy and administrative arrangements to meet International obligations. Australia is a signatory to a (considerable) number of International conventions, including the Convention concerning the Protection of the World Cultural and Natural Heritage (World Heritage sites), the Ramsar Convention, the Protection of Ecologically Threatened Species, and the Convention on Biological Diversity (CBD). These are all are discussed under the EPBC Act.

Responsibility for dealing with all matters outside Commonwealth jurisdiction, including natural resource management of which Geoheritage is a component, that are not related to international agreements, lies with the State and Territory governments (who in turn have traditionally devolved some responsibilities, particularly those relating to land use and development planning, to local governments; Bellamy 2007).

While the 1983 High Court decision is generally viewed as a landmark decision in favour of the environment in that it stopped the flooding of a World Heritage Site, and established Commonwealth powers over sites of National and International significance. In fact, it marked the beginning of the ongoing “deconstruction” of the Australian Heritage Commission (AHC) (established in the Australian Heritage Act 1975) and the Register of the National Estate, and the returning of powers in relation to National Heritage back to the States and Territories. The history of the “deconstruction” of Commonwealth powers, and the initiatives to identify and protect sites of Heritage significance established under the Australian Heritage Act 1975 is an outcome of the establishment of the Council of Australian Governments (COAG), and its recommendations, as described below.

The era of COAG began in 1990 at the special Premiers’ Conference, with leaders and representatives agreeing that there was a need for a framework to improve the functioning of the Australian Federation and setting out a wide-ranging agenda for reform directed towards developing a more efficient and competitive economy through maximising intergovernmental co-operation in the interests of Australia as a whole (COAG 1991). At its 1991 meeting, in relation to matters of the environment, it was agreed that there was a need for an Intergovernmental Agreement of the Environment for more effective national arrangements for setting consistent standards across Australia, and established a working agreement to that end.
For instance, in relationship to the International Convention on Biological Diversity, in 1993 COAG noted that the Commonwealth had consulted with the States and Territories on the implications of Australia ratifying the International Convention on Biological Diversity in accordance with the Intergovernmental Agreement on the Environment. It agreed that the substantive obligations arising from the Convention could be met with only minor changes to the current policy and programme frameworks of Australian governments. The Council supported the Commonwealth in proceeding immediately to ratify the Convention (COAG 1993).

In 1997, the Council of Australian Governments gave in-principle endorsement to a Heads of Agreement which resulted in the fundamental reform of Commonwealth/State roles and responsibilities for the environment. These reforms were intended to deliver more effective measures to protect the environment, and included the following initiatives:

1. Commonwealth responsibilities and interests to be focused on matters which are of genuine national environmental significance;
2. Significant streamlining, greater transparency and certainty in relation to environmental assessment and approval processes;
3. Rationalisation of existing Commonwealth/State arrangements for the protection of places of heritage significance through the development of a co-operative national heritage places strategy (COAG 1997).

In 2006, COAG endorsed the Development of Bilateral Agreements to make the changes set out in COAG (1997) under the Environment Protection and Biodiversity Conservation Act 1999 and to further investigate the streamlining of environmental approvals processes within the existing architecture of the EPBC Act (COAG 2006).

In 2011, on the basis that “The protection of Australia’s unique environment and heritage is a responsibility and priority for all Australian governments” and that “Environmental assessment and approvals processes are a critical means of providing protection for our unique environment, while supporting our economic development” (COAG 2011) Ministers considered that national reforms were needed to better integrate State, Territory and Commonwealth regulatory arrangements for environmental protection, and agreed on the need for major reforms of environmental regulation across all levels of government “to reduce regulatory burden and duplication for business, and to deliver better environmental outcomes, including through greater use of regional planning and strategic assessments” (COAG 2011).

However, while the reforms are reportedly founded on recognizing that protecting Australia’s “unique and environment and heritage” as being a priority, in fact it has been argued that this is not the case and, as such, the changes to the EPBC Act to establish these reforms have been widely criticised. This will be discussed later under the section dealing with the era of the EPBC Act.

**The Department of Environment and its history**
The current Department of the Environment, formed in 2013 (Department of Environment 2014), is the Federal government agency for Environment and Heritage matters, and is responsible for policies for environment and heritage protection Australia-wide. However, since Federation, and more specifically since the first government agency that included a portfolio for Environment in 1971, there have been 16 different portfolios that include the Environment (Australian Government 2015), i.e., the Government Agency that manages environmental matters at the Federal level. This Government agency has been restructured 15 times in 34 years, under 28 Federal Ministers, as follows (the Hon E G Whitlam held the Environment Portfolio 1972 and again in 1975):
2. Department of Environment and Conservation (1972-April 1975)
3. Department of Environment Australia (I; 1975-1975)
4. Department of Environment, Housing and Community Development (1975-1978)
15. Department of Environment (III; 2013 to the present).

These frequent changes in Government, ministerial responsibility, and names of this environment-and-conservation agency, are indications of the rapid changes in directions and strategies that reflect, firstly, a relative instability in government that is driven by political bipartisanism and, secondly, the lack of commitment to stable environmental management in a country that is committed to resource exploitation to maintain its economy (Horne 1964; Brocx 2008). Bellamy (2007) describes environmental legislation and policies that encompass natural resource management as being multilayered, fragmented, and ad hoc.

In the text below, the description of activities and policies for Geoheritage and Geoconservation within this current Federal agency for environment and heritage is one that outlines administrative processes, mechanisms, plans-for-the-future, and legislation. But within this literature and information source the Federal agency generally does not use the word policy. In principle, and with what it intends to accomplish, this literature and information source is, in fact, policy. It also provides some guidance. Further, it presents information on the objectives of Geoheritage and Geoconservation as “work in progress”, a process that has been ongoing now for over 20 years.

A review of the history of Geoheritage and Geoconservation in Australia from the 1800s to 2007 is provided by Brocx (2008).

In more recent times, following on from the focus on heritage in the 1970s by the Whitlam Government, when Heritage came to the political forefront with the proposed damming of Lake Pedder in Tasmania (Brocx 2008), there have been five main phases or eras in the history of Geoheritage and Geoconservation in Australia; these were/are:
1. The era of Australian Heritage Commission (AHC), and the Register of the National Estate (1975-2004) under the Department of Environment Australia to the Department of Environment, Housing and Community Development 1974-1998
2. The era of CRA and RFA (1997-2001) Department of Agriculture in association with other Federal and State Government Agencies (such as the Australian Nature Conservation Agency)
3. the Environment Protection and Biodiversity Conservation Act (1999) and amendments (replacement of the Australian Heritage Act [1975])
5. Present era of Department of the Environment, 2013 +

(The time interval of each phase was relatively short so that the term ‘era’ is used here in the colloquial sense).

Prior to the endeavours of the Whitlam Government, there was little focus on Geoheritage and Geoconservation, with geological features being protected as a criterion of World Heritage sites, by default by being within the boundary of various National Parks or, with the exception of Tasmania, conserved on an ad hoc basis (Brocx 2008).

The era of Australian Heritage Commission (AHC)
This section deals with the achievements and deconstruction of the Australian Heritage Commission and the now-repealed Australian Heritage Act (1975).

Under the auspices of the Minister for the Environment of the day and the Federal Government agency, Environment Australia, the era of Australian Heritage Commission (established under the Australian Heritage Act 1975), and Environment Australia marked the first time when matters of Geoheritage and Geoconservation were directly addressed by the Federal government as part of its political agenda. Through its agencies and commissions, guidelines and criteria were established to identify sites of heritage (including geology), for a National inventory known as the Register of the National Estate. During this era, the government commissioned studies and sought submissions to populate the Register of the National Estate with nominated sites that met the selection criteria, and information on the significance of the site. It also facilitated workshops to bring expertise into discussions on how to progress geoconservation (Eberhard 1997). In 1997, the AHC developed a new approach to selecting sites for conservation with the adoption of ‘Themes - telling a story’. The idea was to make a connection between the landscape and individual sites, and geological processes past and present, with human and cultural aspects (Brocx 2008). Essentially, this approach placed issues of geoconservation into the realm of education and consciousness-raising, and provided a platform for the conservation and management of geological sites where the public became involved. The approach was timely in that a major deficiency in Geoheritage, Geoconservation and protection of geological features is the general lack of texts and publicly-available information explaining Australia’s geology and geomorphology.
The Australian Heritage Commission (1990) developed criteria for selection of areas for the Register of the National Estate (RNE). The criteria were in medium qualitative detail to capture features that might be of national Heritage significance, including attributes of diversity, maintenance of existing regional processes, maintenance of regional natural systems, rarity, historic value (natural and cultural history), representativeness of a range of landscapes, environments or ecosystems, and scientific value. The criteria for selection of an area for the RNE by the Australian Heritage Commission are listed as 4 main types (Table 11.1; Australian Heritage Commission 1990).

Table 11.1: Criteria for site selection for the RNE by Australian Heritage Commission

| 1. Criterion A: Importance of an area or site in the course, or pattern, of Australia’s natural or cultural history; |
| 2. Criterion B: Possession of uncommon, rare or endangered aspects of Australia’s natural or cultural history; |
| 3. Criterion C: Potential of an area or site to yield information that will contribute to an understanding of Australia's natural or cultural history; and |
| 4. Criterion D: Importance of an area or site in demonstrating the principle characteristics of (i) a class of Australia’s natural or cultural place; or (ii) a class of Australia’s natural or cultural environments. |

These criteria embody many geological and geomorphological aspects of geoheritage, encompassing geohistorical features and critical locations (Criteria A, C and D), rare or unusual sites, such as fossil or mineral localities (Criterion B), and areas where there are active processes (Criterion D).

The criteria were to be applied to determine if a site of potential heritage passes a threshold of significance such that it was of national significance. The criteria are not designed to locate/identify geological sites of heritage significance from first principles. But even for what they were designed to accomplish, these criteria were too diffuse to be useful to evaluate sites of geoheritage significance because, in their design, their intention was to assess all manner of sites, viz., cultural, or ecological, or biological, or geological sites, that a priori have very different characteristics and, thus, the criteria had to be broad in scope. Each of the attributes for determination of significance at the National level for Indigenous culture, European culture, building culture, ecology, biology, and geology would be different and so the design of selection criteria by the Australian Heritage Commission (1990) can only be applied at high levels of assessment, i.e., there are no detailed criteria to address site-specific and region-specific features.

Interestingly, even though there have been major shifts in scope, philosophy, and programmers in the pursuit of Geoheritage and Geoconservation by the Federal agency for environment and heritage, the Criteria A – D above have survived to today as the main recipe for assessment of heritage nomination and evaluation (Australian Heritage Council 2009). As noted above, the design of selection criteria is fundamentally flawed, and even now they have not been formally and robustly challenged.
The era of Comprehensive Regional Assessment (CRA) and Regional Forests Agreement (RFA) - 1997-2001

During this era, for the first time, geoheritage significance was considered for conservation and management in forest regions as part of a Comprehensive Regional Assessment (CRA) and Regional Forests Agreement (RFA) between the Federal government and the various States in Australia (Australian Government 2004). The process took place between 1997 and 2001 in eleven Forests Regions in five States, i.e., Queensland, Western Australia, Victoria, Tasmania and New South Wales. The sites of geoheritage significance generally were identified using Australian Heritage Criteria (Australian Heritage Commission 1990), though Semeniuk (1998) rejected the AHC criteria and developed an independent method by utilising geological regions, geologically characterising those regions, undertaking literature reviews, obtaining information and refinement of important geological features from interviews, and determining levels of significance of the geological features. The process and effectiveness of the assessment of geoheritage in these regions has not been without controversy (cf. Osborne et al. 1998) in that some considered the process was not thorough and exhaustive enough.

Environment Protection and Biodiversity Conservation Act 1999

The EPBC Act was founded on the 1997 COAG accord by Commonwealth Agreements with the individual States agreeing to identify and legislate for the protection of natural heritage. Their objective was to:

"define the critical moments in our development as a nation and reflect achievements, joys and sorrows in the lives of Australians; also encompassing those places that reveal the richness of Australia's extraordinarily diverse natural heritage".

In 1999, the Australian government enacted the Environment Protection and Biodiversity Conservation Act 1999 (the EPBC Act) as its central piece of environmental legislation. This provided a legal framework to protect and manage nationally and internationally important flora, fauna, and ecological communities. One of the objectives of the EPBC Act was to provide for the protection of the environment, especially those that constituted “matters of national environmental significance” (NES). Though not explicitly mentioned as a heritage feature, Geology (sensu stricto) and Geoheritage are included in the EPBC Act as “national heritage places”.

However, amendments to the EPBC Act were later undertaken. As a result of amendments to include national heritage as a matter of national environmental significance, provisions enabling the creation of a National List of Heritage Places came into effect on 1 January 2004. As Heritage forms part of Australia's cultural identity, this was to include objects, collections and intangible aspects such as community values, customs, languages, beliefs, traditions and festivals. However, a ceiling level, or cap, was placed on the number of sites that would be protected, viz., 13 000+ natural, historic and Indigenous places in an entire continent.

To put this into context, the change of status and capping of the number of listed places on the National Heritage List means that only a few of the 13 000+ natural, historic and Indigenous places of an entire continent will be listed for protection under new criteria for legislative protection. Currently, there are some 85 sites on the National Heritage List, including World Heritage Sites, and buildings such as the Qantas Hangar at Longreach and places, for example the Melbourne Cricket Ground and the Flemington Race Course. In comparison, the US National Register of Historic Sites alone has over 60,000 places while in the United Kingdom over 450,000 historic places are listed.
While there are some positive aspects to the enactment of EPBC Act in that it does offer strong legislative protection to sites listed under the Act, the negative aspects (particularly for Geoheritage and Geoconservation) include:

1. restrictions as to types and numbers of sites that can be nominated and listed;
2. the decision on what sites are listed is determined by the Minister;
3. there is no systematic inventory-based assessment of sites of Geoheritage significance by the Commonwealth, or by the States (with the exception of Tasmania);
4. only a select few sites of National Significance will be afforded legislative protection;
5. the potential loss of the enormous body of work by the States' Geological Societies, and individuals, under the National Heritage Trust (NHT) funding and the Regional Forests Agreement (RFA) that led to listing of sites on the RNE;
6. there are no defined criteria that allow for sites to be nominated for Science and Education;
7. the EPBC Act is largely directed towards the protection of biodiversity;
8. there is no recognition that geodiversity underpins biodiversity; and
9. there is no avenue for representation by the Geological Society of Australia to present the interests of Science and Education in the Earth Sciences in the selection and protection of sites of geoheritage significance.

The continuation of this state of affairs has resulted, and will result, in non-recoverable damage, or the loss of not only sites that have been identified as of geoheritage significance, but also those that had yet to be identified.

In a global context, save for Tasmania, the current framework of piecemeal and ad hoc conservation of sites of geoheritage significance at the Commonwealth, and State level is over 30 years behind the rest of the world in relation to inventory-based conservation (as discussed in Chapter 10), and at least 10 years behind the rest of the world in recognising the link between geodiversity and biodiversity.

The era of Department of Environment and Heritage through to the Department of Environment, Water, Heritage, and the Arts and the Department of Sustainability, Environment, Water, Population and Communities - 1998-2013

The era of rapid departmental name changes and departmental restructuring, from the time of the Department of Environment and Heritage, the Department of Environment (1998), Water, Heritage, and the Arts, and the Department of Sustainability, Environment, Water, Population and Communities commenced and continued to 2013 after which the Department of the Environment was established. The department dealing with environment and heritage changed its name as Cabinet Ministers for the Environment/Heritage within the government of the day had extra duties tacked onto their main portfolios and new foci (such as ‘climate change’ or water shortages as political issues emerged). Recurring as duties within this changing ensemble of the Portfolio were matters of environment and heritage and so, for this part of the Thesis, all the departments in this era will be referred to as “Department of Environment and Heritage”.

The Australian Heritage Commission, as the Australian Government's independent expert advisory body on heritage matters, was replaced by the Australian Heritage Council, the principal adviser to the Australian Government on heritage matters. The Council is a body of heritage experts established by the Australian Heritage Council Act 2003 when the new Commonwealth heritage system was introduced in 2004 under amendments to the EPBC Act. The Council assesses nominations for the National Heritage List, and the Commonwealth Heritage List.
Early in this era, as outlined above, the Council of Australian Governments (COAG) agreed on the need to develop a more effective framework for intergovernmental relations on the environment including the listing, protection and management of heritage places because the three-tier system of lists at the time was appropriate only for each jurisdiction taking responsibility for its own level of heritage protection (Australian Heritage Council 2007). Essentially the list below identifies and ensures the protection, promotion and management of heritages places at various levels in Australia (Australian Heritage Council 2007):

- World Heritage List
- National Heritage List
- Commonwealth Heritage List
- Register of the National Estate
- State and Territory heritage lists
- local government lists or overlays in planning.

Each of these lists had different criteria and thresholds for selection or nomination of sites (Australian Heritage Council 2007).

Essentially, the National Heritage List is intended to comprise natural, historic and Indigenous places that are of ‘outstanding heritage value to the nation’ (Department of Environment 2014b). National heritage defines the critical moments in our development as a nation and reflects achievements, joys and sorrows in the lives of Australians. It also encompasses those places that reveal the richness of Australia’s extraordinarily diverse natural heritage.

Places in the World Heritage List must be of ‘outstanding universal value’, not only important from a national viewpoint, but recognised internationally as being a critical part of the inheritance of all humanity (UNESCO 2005). The threshold of heritage significance for the National Heritage List also is high, second only to World Heritage but must be of ‘outstanding heritage value to the nation’. This distinguishes them from places that would properly be regarded as places of State or local significance compared with those that are of national significance. The registration criterion for the Commonwealth Heritage List and the Register of the National Estate is that the place has a ‘significant heritage value’ and hence has a qualitatively lower threshold. While no specific limit has been set for the number of places in the National Heritage List, the high threshold results in a much smaller number of places than there were in the Register of the National Estate.

The Australian Heritage Council (2007) agenda appears to address heritage issues in Australia. However, examined in detail, there were inconsistencies and flaws in the approach: 1. the World Heritage List, for instance, largely was a carry-over from a previous era; 2. the State and Territory heritage lists, local government lists or overlays in planning were lists outside the jurisdiction and selection process of the Federal government; 3. the Register of the National Estate was soon to be decommissioned; and 4. the National Heritage List and the Commonwealth Heritage List had an over-emphasis on human, cultural, historic, and Indigenous sites.

Within this era of the “Department of Environment and Heritage” three significant events took place for matters of conservation of heritage and the conservation of geological features.

Firstly, the Register of the National Estate (RNE) was closed in 2007 and replaced by the Australian National Heritage List and the Commonwealth Heritage. Provisions enabling the creation of the National List of Heritage Places came into effect on 1 January 2004. However, in contrast to the RNE (which had over 13,000 properties that had been compiled collectively by National Trusts, heritage agencies, councils, NGOs, and many individuals over the past 25 years), the State of the Environment Report (Anon 2011) reported that The National Heritage List contained 95 places, most of which were added between 2005 and 2008. The most recent addition was the west Kimberley, added on 31 August
Following amendments to the EPBC Act in 2007, the national heritage listing programme is now confined to places on a ‘priority assessment list’ determined by the Minister for the Environment. In practice, this means that the majority of National Heritage List nominations received since 2007 have lapsed without being assessed. As of 2011, there are currently 338 places on the Commonwealth Heritage List, of which only 10 were added between 2005–06 and 2010–11, 87% of which were historic places (Lennon 2006). Thus, the RNE, closed in 2007, is no longer a statutory list, and all references to the Register of the National Estate were removed from the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) on 19 February 2012. As mentioned above, all the work by individuals, NGOs, and government agencies that developed a framework to protect the Natural heritage of Australia (including many sites of geoheritage significance) was effectively lost.

Secondly, following on from the ideas set by the Australian Heritage Commission in the 1990s, the Department of Environment and Heritage embarked on a quest to identify Australia’s geoheritage values with the adoption of ‘Themes - telling a story’. The Australian geological and geomorphic (landscape and environmental) settings were to be captured in several main themes. These ‘themes’ included: arid landscapes (including desert dunes), palaeo-plains, palaeo-drainage systems, fossils, volcanic Australia, karst, and coasts.

While initiated in 2004, to date, the “theme” approach has not led to published outcomes. There have been workshops on some of the themes, with experts invited to contribute to a given “theme” (e.g., rocky coasts of Australia), but there have been little or no definite outcomes in terms of inscription of lands for geoheritage purposes, nor reports that are publicly accessible, nor mention of the themes on the government websites. Today, it is difficult to navigate the plethora of websites that once belonged to the assortment of evolving appellations of the Federal government agency concerned with ‘environment and heritage’ to even find the list of “themes” that were supposed to encapsulate the geoheritage essence of Australia.

However, the Federal government’s journey on the ‘theme approach’ to address geoheritage in Australia was flawed. This approach may capture some of the variation of Australia’s geological and geomorphic heritage, but it does not at all capture the full range of what is geological heritage nor what is geomorphological heritage. Geologically, Australia is a globally unique continent, with the Yilgarn Craton, the Kimberley Craton, the Gawler Craton, amongst other cratons (some extending back to the beginning of the Achaean), and with various Phanerozoic basins from Cambrian to Quaternary in age. Any limited set of geological themes cannot hope to capture the range of geological phenomena that are present in the continent. Further landscape settings and climate-influenced landforms have no relationship to the content and importance of bedrock. For instance, the Canning Coast geomorphology, stratigraphic history, sea-level history, changing style of sedimentation over the Holocene, and the extent of calcilutite accumulation cannot be replicated elsewhere in the World (Semeniuk 2008). Yet this area and its features are not captured by any of the themes of the Department of the Environment. Neither is the variety of geomorphic types, stratigraphic sequences and hydrological mechanisms within the various wetland groups (consanguineous suites of C A Semeniuk 1988) that stand as a globally-unique system of diverse wetlands, or the desert sand to coast transition in the Quaternary of the Swan Coastal Plain (Semeniuk & Glassford 1987, 1988), or the Archaean granitoid domes and folded greenstones that comprise the Pilbara Craton (Geological Survey of Western Australia 1990). All four are globally unique. Therefore, attempting to capture the variability of Australian geology in the limited number of set themes is presumptuous that the full diversity of what Australia has to offer the World in terms of geological heritage can be contained in the predetermined selected themes.
The same principles and comparisons can be applied to the themes of geomorphology in Australia. With its history of migration of the continent from the Antarctic to the equatorial region (thus capturing a long-term climate imprint and change over the Tertiary), and with the various Precambrian cratonic rocks and Phanerozoic basins formerly lodged and now residing in the variable climate of Australia (compare Figure 5.2 with Figure 5.4 to appreciate the potentially interactive variable geology and the variable climate of Australia), the geomorphology of Australia can be quite varied and globally unique. Jennings & Mabbutt (1977) and Gentilli (1979) present maps of Western Australia and of Australia that show the marked geomorphological diversity of land systems across the continent. From the perspective of these geomorphological maps, it cannot be said that the diversity of the geomorphology of Australia has been captured by the limited number of set themes across the continent proffered by the Department of the Environment.

The third major event in this era was that development-oriented members of COAG, particularly Queensland and Western Australia, in concert with a development-oriented Federal government, worked towards effectively dismantling the EPBC Act (COAG 2011). Powers of assessment for projects and the significance of heritage matters were handed to the States so that instead of an ostensibly neutral Federal government that would be making assessment on matters of development-versus-heritage, the task of assessment was handed to the State that was proposing and regulating the development.

Coastal heritage is addressed in the 2011 report on the Australian-Government-commissioned State of the Environment, but it is not coastal heritage in the sense of natural heritage (Anon 2011). The report states that:

“Many Australian natural heritage places are in coastal areas. Many important wetlands, for example, occur on coastal plains, which are especially vulnerable to degradation both because they are often accessible and close to population centres and because they are at the end of river systems that have had water extracted for various uses before it reaches the coast. Because Australia was initially settled around its coasts, coastal areas have many buildings of heritage significance and historically important shipwrecks. Conditions that degrade buildings and natural structures (e.g., wind, salt, inundation) are often more extreme in coastal areas, requiring particular attention to the preservation of heritage assets. Indigenous places of cultural significance in the coastal zone are potentially under threat from the same forces that affect natural heritage.”

So here, clearly, the State of the Environment report views coastal heritage as cultural heritage.

In May 2012 the Department of the Environment, after its first call for submissions on developing a National Heritage Strategy, commissioned an essay on geoheritage by Dr Graeme Worboys. The essay was added to the Australian Heritage Strategy website (viz., Worboys 2012). From this perspective, geoheritage appeared to be still on the Department’s agenda.

On a final note – a review of the literature on ‘heritage’ held by the Department of the Environment shows an over-emphasis on historic building sites, (European) human endeavours, cultural heritage, Indigenous heritage. This is not to say that these forms of heritage are unimportant, but the matter of Earth history heritage and the unique geology that characterises the essence of geological Australia, and that in fact underpins the biodiversity of Australia, were largely ignored. For instance, with its sporting ethos, Australians have elevated the Melbourne Cricket Ground to a national icon and, as such, it is listed on the Victorian Heritage Register and was one of the first sites to be included on the Australian National Heritage List in December 2005. It is referred to within Victoria as the “Spiritual Home of Australian Sport”. In contrast, what should be iconic geological and geomorphological sites in Australia have been ignored and not given their due status.
**The Present era - the Department of the Environment**

The Department of the Environment was established on September 2013. So far its main contribution has been to invite and canvass experts, NGOs, and State agencies within Australia to provide input into its Heritage Strategy. This was accomplished by sending out a draft of its heritage policy and then holding half-day workshops in the capital cities of Australia (Department of Environment 2014a). While it solicited submissions for Heritage of Australia, in its draft document for consultation it had entirely left out Geoheritage as a component of heritage, and had not listed the Geological Society of Australia as a major stakeholder. However, in its current structure heritage has been combined with Wildlife and Marine as a matter of Environmental Protection. While funding for management of World Heritage areas and IUCN Parks Areas from the Federal Government is via the National Regional Management (NRM) Caring for Country Programme, its focus is on biodiversity. In a joint Department of Environment and Department of Agriculture Report titled *Achievements Report Biodiversity and Natural Icons* 2008-2013 (under the National Landcare Program, all achievements in relation to Natural Icons were related to biodiversity (NLP 2013).

The most recent study oriented towards definition and principles of Geology, Geoheritage, Geoconservation, and Geodiversity, was commissioned by the Department of the Environment in their review of the scope of the EPBC Act. This was the essay by Worboys (2012). However, even though Worboys completed the study and posted it on a website (Worboys 2012), the Department of the Environment ignored it in its review of the scope of Heritage in the EPBC Act, and in its Heritage Strategy (Department of Environment 2014a, 2014b).

**Summary**

Initially, in the 1990s through to the early 2000s, the Federal departments and agencies for environment and heritage provided guidance, policy, and legislation to deal with Geoheritage and Geoconservation as part of its environmental and heritage governance. However, today, although the Department of the Environment is a Federal government body that deals with the triad of Nature, Conservation, and Parks but provides no information, direction, or strategy on how to manage geology, geoheritage, and geoconservation as part of the conservation estate. The reality is that since the mid-1990s, when some initiatives in Geoheritage and Geoconservation were being taken, in twenty years the Department has carried out very little to advance geological conservation. What it has retained from the earlier strategies and policies, and where it is going in terms of Geoheritage and Geoconservation, should be viewed as very incomplete ‘work in progress’.

While it acknowledges or has acknowledged sites on the World Heritage List, the National Heritage List, Commonwealth Heritage List, Ramsar wetland sites, and the (former) Register of the National Estate, the work by the Federal government agency for environment and heritage is not to global standards and consequently some of the Australian sites are threatened with being de-listed (*e.g.*, The Coorong; Keith *et al*. 2013), and there is global attention focused on World Heritage sites such as the Great Barrier Reef because of anthropogenic impacts from a development-oriented and resource-exploitative government and community (Gladstone Ports Corporation 2012).

The Heritage work and its literature by the Australian Federal government, which is supposed to present the heritage interests of the entire Australian nation, are poorly organised, poorly conceptualised, and poorly presented. Readers and researchers have to meander through Department name changes, and attempt to find information that is (non-hierarchically) embedded in weblinks and sub-weblinks. The Heritage work and its literature are not comprehensive, and form no model that one could emulate.
Further, though not stated explicitly, the “Themes” that appeared in earlier documents (i.e., past records of the personnel who were in decision-making positions) appear to have been selected as a manageable reporting and funding framework. i.e., the reporting framework required under the EPBC Act. But the “Themes” were established by non-geologists, rather than being a science-based geological framework as established, for instance, in the United Kingdom by geologists from the Geological Society of London and those working for the (then) Nature Conservancy Council, probably in consultation with the academic community, some of whom may have been members of the Geological Society of London. The “Themes” in Australia have been selected without a thorough understanding of what constitutes the geological “essence” or geoheritage “essence” of Australia.

Critical to the lack of focus on geoheritage and the addressing of heritage values of Geology in Australia is the fact that the Department of the Environment (and most of its predecessors) in its Heritage section had no geologists on staff (Brocx 2008; and personal interviews).

Another one of the key aspects of heritage conservation in Australia today is that there is nothing explicit on websites and publications by the Federal government agencies relating to Geology, Geoheritage, and Geoconservation. The wording in policies, guidelines, Acts, annual reports, and position statements refers to Natural heritage but the undertone is one of protection of heritage that is biological. If there is reference to physical and abiotic aspects of the environment it usually relates to landscape as the habitat for biology, the emphasis is clearly biological. Nowhere are there explicit statements such that a site which might be the equivalent to Hutton’s unconformity at Siccar Point or the chalk cliffs of Dover (both of which would have no biological or ecological significance) would/should be preserved for the sake of geology. Federal government agency officials, in discussions about this matter, point out that geology is alluded to or is implicit, but allusions and implicit definitions will not stand up in a Court of Law nor help to preserve a geological feature against the threat of an economically-beneficial development.

In terms of coastal heritage (and this is explicitly not ‘coastal geoheritage’, but coastal heritage in the sense of historic and human heritage), Australia still does not have a comprehensive, nationally consistent system for measuring the condition and trends of its coasts and ocean ecosystems, and the key resources they support. And Australia, at the Federal level, has not even begun to address the matter of coastal geoheritage.

Consequently, at the National level, the Department of the Environment (and most of its predecessors) provides no useful models for Policy and Legislation for Geoheritage and Geoconservation.

**The Geological Society of Australia Inc. (GSA)**
The Geological Society of Australia Inc. (Geological Society of Australia 2012) was established as a non-profit organisation in 1952 to promote, advance and support Earth Sciences in Australia. The Society’s members represent all Earth Science professions, including geologists, geophysicists, geochemists, palaeontologists, geotechnical and engineering geologists, environmental geologists, and associated professions.

The policy of the GSA for Geological Heritage (Geological Society of Australia 2012) reflects its concern regarding the documentation and protection of various sites and features of significance at National, State and local levels. The GSA defines geoheritage as:

*Significant geological features (SGF) are those features of special scientific or educational value which form the essential basis of geological education, research and reference. These features are considered by the geological community to be worthy of protection and preservation.*
The GSA Heritage Policy - Geological Heritage in Australia
There are six objectives of the Society’s Standing Committee for Geological Heritage (formerly Geological Monuments); the first four are to:

1. promote the understanding and conservation of the geological heritage of Australia;
2. liaise with Divisional Subcommittees in the formulation of criteria to be used for the selection of geological features worthy of protection and preservation in the national interest;
3. identify, document and evaluate the significance of geological features through the various divisional Subcommittees;
4. maintain liaison with the Australian Government and Australian bodies on matters such as the National Estate.

The final two objectives of the Geoheritage Policy of the Geological Society of Australia are administrative, viz., (5) to make recommendations to the Society’s National Executive Committee on geological features proposed by the Divisions for National Estate listing, and (6) to collect and collate annual reports of divisional Subcommittees and present regular reports to Council.

The GSA has policy in relation to sites, features, monuments. GSA uses the terms sites and features to describe respectively areas of small or large extent, or aspects of geology and geomorphology such as a fossil locality, a type section, a landform or other geological features that may have no particular extent. The term geological monument has been used for sites and features that have been recognised as significant. The Society now uses the following definition: Outcrops of rock which have special significance for revealing fundamental aspects of geology and geological history.

The GSA has Divisional Subcommittees and each of these Subcommittees are concerned with geological heritage in each State Division. They have as their principal objectives promotion of the understanding and conservation of the geological heritage in their State or Territory by:

1. identification of sites and features;
2. documentation of such sites and features, in a suitable form;
3. evaluation of sites and features in terms of their significance, normally assigning a level of significance from local, through regional, to national and international; and
4. assisting in the management of sites, by monitoring and promoting their protection for geological reference and research, and for education.

The Subcommittees in each Division maintain for their State or Territory a separate published and unpublished inventory of sites and features and, where assessed, their significance levels, whether local, regional, state, national or international. This also involves the recognition of new sites and features, and the reassessment of sites and features in the inventory from time to time. Reassessment is required by the changing nature of geology as a science as new concepts develop, by the changing needs of the geological community, and because sites and features may undergo changes in their values due to natural and human activities. The preparation and distribution of reports on this work, either covering the whole state or territory, or as a series of regional reports, is the responsibility of each local Subcommittee. In addition, a current list of sites and features of National and International significance with short descriptions is maintained by the Convenor of the Standing Committee, and draws on the work and recommendations of the Subcommittees. The assessment of significance of geological sites and features is carried out by each Subcommittee using criteria developed within their state or territory over many years of work. These criteria may vary in detail in each Division, but they
are basically similar to those used by other divisions, by the Standing Committee and by the Australian Heritage Commission. Criteria include geological type, geological age, use, representative or outstanding nature, rarity and current condition. Promoting the management of sites and features includes activities such as the distribution of information, the preparation of descriptive material and the provision of advice to owners and managers. The rights of private owners must be taken into account when promoting management activities. Listing in the Register of the National Estate did not give automatic access to such places.

The GSA in its Geoheritage Policy has a programme to liaise with Australian Government bodies: The National Standing Committee Convenor has a co-ordination role with regard to the work of the Subcommittees, maintains contact with the Subcommittees, usually by correspondence, and organises opportunities for discussion and co-ordination of conservation work in seminars, workshops and business meetings for the Standing Committee. The Convenor of the Standing Committee is/was the Society's contact for day-to-day liaison with Australian Government bodies, and in particular, with the Australian Heritage Commission.

Regular reports of the activities of the Subcommittees are made to the membership of the related Division. The Standing Committee reports to the Executive and Council of the Society. Information is also regularly supplied for publication in The Australian Geologist. However, currently, neither geoheritage nor the GSA are recognised by the Federal Department of Environment in its national heritage Strategy.

The National Trust (Australia)
The National Trusts of Australia, officially the Australian Council of National Trusts (ACNT), are community-based, non-government organisations, committed to promoting and conserving Australia's indigenous, natural and historic heritage through its advocacy work and its custodianship of heritage places and objects. The Trust achieves this objective through the conservation and interpretation of heritage places it manages on behalf of the community and government of Australia, and through its education and learning programs. The National Trust is supported by the Federal Department of the Environment (and its former departments). It was incorporated in 1965, and federates the autonomous National Trusts in each of the Australian States and internal self-governing territory, providing them with a national secretariat and a National and International presence.

While it is stated in its Mission Statement that it is concerned with indigenous, natural and historic heritage, the focus of the National Trusts of Australia is historic buildings and most of its activities are on acquisition, protection, and management of these old sites. In the field of natural heritage, the National Trust has been an advocate for protection of natural environments including geological systems (Halligan 1994 ), but has not developed its own scheme of proactive nature conservation, either in the biological environment or in the geological realm. Its website (National Heritage Trust of Australia: http://www.nationaltrust.org.au/) makes no mention of any sites that are conserved or protected for Geoheritage values.

The National Trust has been assessing and classifying places since the late 1960s and the List includes buildings, precincts, cemeteries, natural landscapes, geological monuments (‘geological monuments’ as defined by the Geological Society of Australia), historic sites, railway vehicles and other items for their heritage significance. There are currently over 1,700 classified items on the list as at 2014 (http://www.nationaltrust.org.au/wa /heritage-register). However, the National Trust’s List of Classified Places does not have a statutory role - its purpose is educational in that it supports our advocacy activities, the establishment of Heritage Appeals as well as being an important record of Western Australia’s heritage.
As a non-government organisation the National Trust has been vocal in protesting the dismantling of the Register of the National Estate (RNE) which, as noted earlier, was a register of Nationally significant (biological, geomorphological, and geological) sites accumulated through submissions and nominations over more than 30 years. Its protest of this Federal government action by the former Department of Environment, Water, Heritage, and the Arts is documented by Brocx (2008).

The National Trust, in its submission to the 2006 amendments to the EPBC Act expressed concern that the amendments put Australia’s heritage at risk, stating that the loss of the RNE (EPBC Act and the Australian Heritage Commission [AHC] Act 1975, 1990) puts at high risk hundreds of heritage-listed sites Australia-wide that do not have protection from any Commonwealth, State, Territory or local government legislation. Under the Act, from February 2007 no more places may be entered on or removed from the RNE, and by 2011 all reference to the RNE will be removed from the AHC Act and the EPBC Act (National Trust Australia 2006). In addition, the National Trust asserts that: 1. the new process is a move away from the established best practice for heritage conservation; 2. in particular it affords the Minister total discretion regarding the scope of the National Heritage List (NHL) and the timing of the assessment of places for the NHL; this can lead to delays and the side-lining of inconvenient nominations; 3. the new processes lack transparency with respect to ministerial decisions and the reasons for those decisions; 4. there is a real need for an initiative to expand the NHL to take over as the pre-eminent heritage list if the RNE is to be abolished; 5. a Minister has over-riding discretionary powers with respect to emergency listing; and 6. stated objectives of the amendments do not inspire confidence regarding the commitment of the Federal government to protect the national heritage (they are more geared to assist development; op.cit.). Further, the new Section 158A sets a decision in concrete and does not allow new, relevant information about the heritage significance of a place to be taken into account after the original decision has been taken. These arguments relate to Geoheritage and Geoconservation because many of the sites listed on the RNE were sites of geological content and sites of geoheritage significance.

Other than this protest in 2006 against the dismantling of the Register of the National Estate, and its declaration that its interest was in Indigenous, natural and historic heritage, the National Trust is not active or proactive in the field of Geoheritage and Geoconservation.

**Policy and Legislation in relationship to Geoheritage and Geoconservation in the various States of Australia (other than Western Australia)**

Policy and Legislation in relationship to Geoheritage and Geoconservation are described below for Tasmania, New South Wales, Victoria, and South Australia. Queensland is not considered because it is similar to Western Australia. The focus in this section will be on Tasmania because in many aspects of geoconservation it has been a leader in Australia.

**Tasmania:**

Tasmania is the only jurisdiction with a conservation agency in Australia with a fully functional Earth Science department committed to the day-to-day integrated management and protection of geoheritage. Geoconservation was raised in profile with the engagement of a permanent, full-time Earth scientist in the Parks and Wildlife service and a geomorphologist in the Forestry Commission whose main responsibilities were the protection of geodiversity. Although conservation of outstanding caves and scenic landforms had taken place since the 1800s, the first milestone in the conservation of sites of geological significance was marked by the Geological Society of Australia’s “geological monuments approach” (centred on bedrock features) of identifying sites of scientific importance beginning in the 1970s. Sharples (2002) describes geoconservation as having undergone three major stages of development in Tasmania, *i.e.*, conservation for scenic values, conservation for scientific values, and integrating conservation with land-management. In addition, the conservation of karst can be seen as an outcome of Tasmania’s history of recreational caving groups established for Tasmanians and visitors, and a statewide inventory undertaken by Kiernan (1995).
A history up to 2007 of the main events for geoconservation in Tasmania, distilled from Brocx (2008), is presented in summary form below, and shows that in spite of its natural resources that could be exploited, it has been relatively progressive in the pursuit of geoconservation. However, even at that time there were no conservation policies for Geology and Geoheritage, and Geoconservation.

During the 1960s-1990s development of land, regardless of tenure, became a public concern, and was no longer an issue between the Government of the day and developers. As outlined earlier, the Federal Court test case to prevent the controversial flooding of the unique Lake Pedder landform “assemblage” in the 1960s by a hydro-electric development is widely regarded as the issue that launched environmental politics in Australia (see discussion in Brocx 2008).

The history of geoconservation in Tasmania is presented by Anon (2014c) as following three major stages: 1. the conserving for scenic values where outstanding caves and areas of scenic landforms were reserved; this is considered to mark the beginnings of geoconservation work in Tasmania; the first work, however, was centred around the ‘Geological Heritage’ or ‘Geological Monuments' approach of the Geological Society of Australia; 2. the conserving for scientific values where there was focus on recognising the scientific heritage value of bedrock features which inform about the Earth's past development; this resulted in two inventories of bedrock sites and some landform features (Jennings et al. 1974, Eastoe 1979); and 3. integrating geoconservation with land management where there is management of landforms and soil processes to prevent hazards such as landslips and subsidence which may impinge on the use of certain areas (Anon 2003).

In 2002, Legislation was enacted (National Parks and Reserves Management Act 2002) to provide for the management of national parks and other reserved land, to repeal the National Parks and Wildlife Act 1970 and related Acts and for related purposes – the objective of this Act was the conservation of the fauna, flora and geological diversity of the State, and to provide for the administration and management planning of national parks and other reserved land, and for related purposes.

Since the review by Brocx of Geoconservation in Tasmania up to 2007 (Brocx 2008), Tasmania appears to have taken a step backwards: the very recent literature dealing with Geodiversity focuses on landscapes, and the relation between landscape/geodiversity and biodiversity and does not deal with the wealth of geoheritage features in the State directly and, as yet, there still are no policies for Geology, Geoheritage, and Geoconservation. For instance, the Department of Primary Industries, Parks, Water and Environment (DPIPWE 2013) published a Natural Heritage Strategy to guide conservation and management of Tasmania’s natural heritage from 2013 to 2030 (DPIPWE 2013). The goals and objectives of the strategy are underpinned by broad principles that guide how the strategy will be implemented, as well as providing direction for nature conservation programs managed by the Department of Primary Industries, Parks, Water and Environment. The strategy provides direction generally for the conservation of natural heritage in Tasmania. In this strategy, both biodiversity and geodiversity are identified as components of Natural Heritage, and the guidelines are set up to monitor, conserve, and manage it. However, references to key geoheritage/geoconservation work by Kiernan, Pemberton, and Sharples are missing, and words such as ‘geology’ and ‘geoheritage’ are wholly absent from the document, while geodiversity is more definitively linked to biodiversity, providing an emphasis that the only relevance of geodiversity (and, by association, the geological sciences) is its underpinning of biodiversity and its support of ecosystems.

The work of earlier authors who provide the principles and information to set up a database has not been lost (because it is available through the website The Tasmanian Geoconservation Database 2014), but its access and reference through a major strategy document (such as DPIPWE 2013) that is intended to take Tasmania’s natural heritage from 2013 to 2030 is missing.
Work on the *Tasmanian Geoconservation Database* (TGD) is ongoing (Tasmanian Geoconservation Database 2014). Founded in 1979, the Geological Society of Australia (Tasmania Division) report, *Geological Monuments of Tasmania*, is a descriptive list of fifty or so geological features and landforms ranging in scale from individual rock outcrops and cuttings that expose important geological sections, to landscape-scale features that illustrate the diversity of Tasmania's geomorphic features and processes (Comfort & Eberhard 2011). This was a precursor of more detailed inventories by the Parks and Wildlife Service and the (then) Forestry Commission from the 1990s onwards. These and other sources were compiled as a single digital dataset as part of National Estate component of the 1997 Commonwealth-Tasmania Regional Forest Agreement. In 1999, the Department commenced active management of the geoconservation database. An expert panel, the Tasmanian Geoconservation Database Reference Group, was convened to assess site nominations and amendments. This panel brings together expertise in different aspects of the earth sciences. The current members include scientists from the University of Tasmania, industry and government departments and its current Terms of Reference can be found below. The *Tasmanian Geoconservation Database* was published in 2006 and is updated annually (The latest version of the *Tasmanian Geoconservation Database* (version 7) was published in 2010). Thus the *Tasmanian Geoconservation Database* (TGD) is a source of information about Earth Science features, systems and processes of conservation significance in Tasmania. It evolved when a number of sources were compiled as a single geoconservation digital dataset as part of the National Estate component of the 1997 Commonwealth-Tasmanian Regional Forest Agreement. The database is accessible to the public through Departmental websites and it is used as a planning tool in land management and in assessing development proposals at various scales. Under Tasmania's three major environmental codes of practice, the database must be consulted and certain actions are prescribed where a geoheritage site is present (Comfort & Eberhard 2011).

**New South Wales, Victoria, and South Australia**

The States of New South Wales, Victoria, and South Australia have varied treatment of Geoheritage and Geoconservation in terms of policy and legislation. In effect, the outline of Geoheritage and Geoconservation in Tasmania is applicable to these States to varying degrees. For instance, all States have databases that record sites of geoheritage significance (Wakelin Associates 2009; Geological Society of Australia, South Australian Division 2013), but there is variable emphasis in geoconservation that reflects the expertise in government circles, and the history of the geoconservation driven by individuals. In South Australia, with close liaison between the Geological Survey of South Australia and the South Australian Division of the Geological Society of Australia, the geological sites nominated for the Register of the National Estate were incorporated into a register of geosites that are afforded protection (Geological Society of Australia, South Australian Division 2013). In New South Wales, there has been an emphasis on karst features and palaeontological localities as geosites (Department of Environment & Climate Change NSW 2008a, 2008b, 2008c; Percival 2014). A review of geoconservation and geodiversity in New South Wales was undertaken by Osborne (2000). Some of the work in recognising sites of geoheritage significance in New South Wales was undertaken as part of the assessment of natural values of regions as part of the Regional Forest Agreements between the Commonwealth and the States (e.g., Osborne et al. 1998). Interestingly, in accord with the view in the rest of Australia, the New South Wales Heritage Office (2005) in its publication ‘Heritage Information Series - A guide to the Heritage System’ has no mention of the words ‘geology’, geoheritage’, or ‘geoconservation’. So, at one extreme in New South Wales, one agency (the Department of Environment & Climate Change NSW) recognises geoheritage values while another (the New South Wales Heritage Office) does not see geology as part of heritage.
Policy and Legislation in relationship to Geoheritage and Geoconservation in Western Australia

Policy and legislation in relationship to Geoheritage and Geoconservation in Western Australia are discussed for the key agencies and organisations that deal with geology and/or conservation. These are: the Geological Survey of Western Australia, the Geological Society of Australia (Western Australian Division), the National Trust WA, The Heritage Council, the Environmental Protection Authority of Western Australia (EPA-WA), the Western Australian Planning Commission, and the Department Parks and Wildlife.

Geological Survey of Western Australia

The Geological Survey of Western Australia maintains its own database of internally assessed sites of geoheritage significance, and may conserve sites of geoheritage significance under the Land Administration Act (1997), and regulates access, via an Environmental Approval process under the Mining Act (1978) as the manager/custodian of sites of geoheritage significance in Western Australia. As such, it maintains a website dealing with Geoheritage and Education in Western Australia (Geological Survey of Western Australia 2013a, 2013b). Within the website, there are links to three Records of the Geological Survey of Western Australia: 1. management plans for the eight “State Geoheritage Reserves” (Grey et al. 2010) which outlines procedures and guidelines for the sustainable management of the recently designated State Geoheritage Reserves in Western Australia; 2. a description of Geoheritage Reserve R50149 which specifically focuses on the geology and evidence for early Archaean life in the Pilbara Craton of Western Australia (Hickman et al. 2011); and 3. a guide to planning, collecting, and procedures when visiting geological sites in Western Australia (Grey 2002). Most of the State Geoheritage Reserves are located in Precambrian rocks in the Pilbara region, or are meteor craters. At present, the established State Geoheritage Reserves fall into two main categories: those related to evidence of early life (fossil sites), and those related to meteorite or asteroid impact structures. Currently, six reserves containing Earth’s earliest visible traces of life at ca 3500 million years ago in the Pilbara region, and two reserves recording much younger asteroid or meteorite impacts, are recognised as requiring special State management because of their exceptional geoheritage value. A primary goal of State Geoheritage Reserves is to restrict sampling to scientific purposes and minimise the impact of such sampling.

Management is also intended to avoid unnecessary duplication of sampling and scientific investigations by different research workers, and to approve only those projects likely to produce significant new results (Grey et al. 2010).

The Geological Survey of Western Australia also provides an interactive map showing locations of site of geoheritage significance. Additionally, the Geological Survey of Western Australia maintains a database of sites of geoheritage significance that are sites not afforded status as “State Geoheritage Reserves”. This database is largely based on the work of Lemmon et al. (1979) and Carter (1987) who were commissioned by the Australian Heritage Committee to investigate the scope of geoheritage sites in specific regions.

In terms of policy, apart from a focus on legislation directed to the public to prohibit collection or destruction of rocks and fossils from the nominated “State Geoheritage Reserves”, there is no policy or guidelines to deal generally with sites of geoheritage significance and no guidance on how to identify further sites of geoheritage significance. There is also no scope for interaction between the Geological Survey of Western Australia and other organisations and bodies such as non-government organisations, community groups, and expert and interested individuals.
There actually has been a large amount of work carried out in mainland Western Australia and in the coastal zone, beyond that of Lemmon et al. (1979) and Carter (1987), that can be accessed from the literature to identify sites and assess them as to their geoheritage significance (using Brocx & Semeniuk 2007, or other established methods of evaluations). The work and recommendations for numerous sites of geoheritage significance are not addressed by the Geological Survey of Western Australia in their database of sites of geoheritage significance. These include the following works: 1. Semeniuk et al. (1988) in their study of coastal dune landforms along south-western Australia; 2. C A Semeniuk (1988) for the consanguineous wetland types of the Swan Coastal Plain; 3. Semeniuk (1998) in a study of geology and geoheritage in south-western Australia for the Regional Forests Agreement Study; 4. Semeniuk & C A Semeniuk (2001) for geoheritage sites on the Swan Coastal Plain; 5. C A Semeniuk (2007) for the globally significant Becher Wetlands; 6. Brocx & Semeniuk (2007) in identifying various locations across Western Australia; and 7. Brocx & Semeniuk (2011a) in their study of Leschenault Peninsula and its estuarine lagoon. In fact, one of the most important geoheritage sites in Western Australia and the World is the globally significant occurrence of Archaean zircon crystals in the northern Yilgarn Craton that records the oldest crystals on Earth (Wilde & Pidgeon 1990; Wilde et al. 2001; Cavosie et al.2004; Brocx & Semeniuk 2007, 2010b) – this site was not recognised by the Geological Survey of Western Australia as a “State Geoheritage Reserve”.

For Western Australia, Semeniuk (1998) developed a rationale and method to identify sites of geoheritage significance [viz., for a given geological region there should first be an extensive review of the literature of the geology for that region, then characterisation of the main geological attributes of that region, followed by a selection key sites based on robust criteria, then followed, where possible, by interviews with geologists and authors of papers describing geological sites to refine or to augment the selection of sites, finally assessing the sites as to their significance]. The Geological Survey of Western Australia has not addressed issues of selection of sites of geoheritage significance using this approach, nor used any other globally-recognised system of compiling an inventory of significant sites. For instance, it has not kept its database of sites of geoheritage significance up to date. For the size and geological complexity of Western Australia, the number of sites in the geoheritage database held by the Geological Survey of Western Australia vastly under-represents sites of geoheritage significance in the State. Also, specifically relevant to this Thesis, there are no sites of geoheritage significance for coastal geoheritage recognised or listed by the Geological Survey of Western Australia.

In this context, there are no relevant works by the Geological Survey of Western Australia in the field of geoheritage generally for policy, nor work in the arena of coastal geoheritage.

**Geological Society of Australia (Western Australian Division)**
The Western Australian Division of the Geological Society of Australia has no further policies in relation to geoheritage and geoconservation than what is presented by the National Convenor of the Geological Society of Australia as described above.

**Heritage Council of Western Australia**
The Heritage Council is the State Government’s advisory body on heritage matters. It is vested with functions and powers under the Heritage of Western Australia Act 1990. The Heritage Council determines the organisation’s strategy, policies and makes key decisions on places to be entered into the State Register of Heritage Places and development referrals. Currently, there is no geologist or Geoheritage practitioner on the Heritage Council.
**National Trust WA**
The National Trust of Australia (Western Australia) is the Western Australian Chapter of the National body described above. The National Trust of Australia (WA) is the pre-eminent community-based organisation promoting the conservation and interpretation of Western Australia's unique heritage, and educating the community about the use of cultural heritage (historic, natural and Aboriginal) for the long-term social, economic and environmental benefit of the community. It works to raise knowledge, awareness, understanding and commitment to Western Australia’s natural, Aboriginal and historic heritage. The Trust achieves this through the conservation and interpretation of heritage places that it manages on behalf of the community and government of Western Australia, and through its education and learning programmes.

The National Trust of Australia (WA) is involved with government agencies and other non-government organisations to help conserve heritage sites and to operate covenanting programs to protect high conservation value areas on private property (National Trust of Australia Western Australia 2005). For instance, since 2000, the area of private land registered under the Department of Parks and Wildlife (formerly the Department of Environment and Conservation) and National Trust conservation covenanting programmes has tripled to approximately 250,000 ha. Several other programmes involve conservation on private land including BushBank, the Australian Bush Heritage Fund and the Gondwana Link. However, the National Trust of Australia (Western Australia) has primarily been focused on conservation and protection of ecological areas (as noted above), cultural sites (such as heritage buildings), enquiry-based education programmes (that facilitates heritage education using National Trust properties as a resource), and archaeological/cultural areas (such as the Dampier Rock Art Precinct; National Trust of Australia, Western Australia 2005).

In recent years, landscapes are gaining more recognition in the National Trust of Australia (WA) Classified List, although this list does not formally protect cultural landscapes. Geology and Geoheritage, as aspects of Natural heritage, have not as yet been formally recognised by the National Trust of Australia (WA) and there are no policies or position statements in this regard.

**The Environmental Protection Authority of Western Australia (EPA-WA)**
The Environmental Protection Authority of Western Australia (EPA-WA), established in 1972, is a statutory authority within the Government of Western Australia that has been providing advice and recommendations on environmental matters for over 40 years. The EPA-WA provides advice to the Minister for Environment through various reports, as well as releasing statements to the public about significant environmental matters. It is the primary provider of independent environmental advice to the government.

Most of the policies, assessments, and recommendations by the EPA-WA in relation to environmental protection are focused on biota and human health. Following patterns set globally, its policies effectively are recommendations and implementation of environmental management plans for critical areas where there is pollution or dredging or greenhouse gas emissions, other polluting gas emissions, or other perturbations to the environment. Though there is no formal policy in relation to geoheritage and geoconservation, the EPA-WA has addressed geoheritage in Western Australia through its *State of the Environment* reports (e.g., Environmental Protection Authority 2007, 2013), and in some of its responsive reports and assessments of proposed developments.
One of the most important documents published by the EPA-WA is its ‘Environmental Guidance for Planning and Development’ (Environmental Protection Authority of Western Australia 2008a). Here, in providing environmental guidance, it has addressed landscape, some aspects of geology therein (as it relates to the development of landscape), and karst in its Guidance Statement on biophysical factors in planning and development.

In its guidance notes for planning and development the EPA-WA provides key environmental factors that are used by the EPA-WA in its environmental impact assessment process. These include environmental geology maps. And in its guidance notes for management plans for wetlands and karst areas, the EPA-WA recommends that the proponent of any development undertake study of the geology, landform, landscape and soils, and geological features that influence a waterway or a karst feature. Further within the guidance notes, the EPA-WA provides advice on management of natural areas for urban and developed areas with important or near important natural features, rural farming areas and other areas where landscape values depend on natural resources. In this regard, landscape refers to the appearance of the land, including its shape, texture and colours, reflecting the way in which these various components combine to create specific patterns and pictures that are distinctive to a particular locality; it relies on other influences for its character, such as underlying geology, and soils, the topography, archaeology, landscape history, land use, land management, ecology, architecture and cultural associations, all of which can influence the ways in which landscape is experienced and valued.

Thus the EPA-WA provides detailed guidance on how to manage landscape and how not to degrade landscape, and geology is referred to only in the sense that it is useful and necessary to understand only to manage the environment. There is no emphasis on geology to protect geological features of significance, i.e., sites of geoheritage significance. There are no guidelines and policies on geology to preserve geological features such as stratigraphy, tectonic structures, fossils, or minerals. Hutton’s unconformity, Lapworth’s mylonite, the Jack Hills zircons, a Western Australian type stratigraphic section, or globally-significant geological interfaces such as the K/T boundary (Cretaceous/Tertiary boundary) in the Global Boundary Stratotype Section in Italy would not be recognised or preserved.

In its overview, in terms of EPA-WA philosophy, the EPA-WA recognises that Natural Heritage areas are valued for their biological and physical features (in this case ‘physical features’ equates to ‘geological features’) and that these biological and physical (geological) features may be significant in terms of their existence or intrinsic values, or in terms of their social, aesthetic, life support or scientific values for both present and future generations (Lennon et al., 2001). They may also have cultural or spiritual significance. Natural Heritage places can be diverse and include such things as landscapes, waterways, desert mound springs, or marine or bushland ecosystems. Geological features that are important for understanding Earth’s evolution are also included in the notion of Natural Heritage by the EPA-WA, and these may include significant geoheritage features such as important fossil localities, rock relationships, type sections, significant landforms (e.g., mountains, outcrops) or other geological or geomorphological features that are unique or considered scientifically valuable.

But while currently there is no system for formal recognition of geoheritage, the EPA-WA has recognised the geoheritage work of the Geological Society of Australia in identifying the various (approximately 150) significant geological sites in Western Australia by Carter (1987) and Lemmon et al. (1979). These are often addressed in the deliberations of the EPA-WA in its assessment of development proposals. For instance, conditions may be placed on mining tenements that cover geoheritage sites. However, the EPA-WA recognises that there is currently no formal protection mechanism that covers all geoheritage sites.
There are three notable reports where geoheritage was a key factor in recommendations by the EPA-WA to preserve or strictly manage a terrain in its responsive reports and assessments of proposed developments: 1. the proposed use of the Doctors Creek tidal flats (in King Sound – see Semeniuk & Brocx 2011) where tidal-flat wild lands, mangroves and tidal creeks were the critical environmental/geoheritage features that resulted in rejection of the proposal (Environmental Protection Authority of Western Australia 1999); 2. the proposed Alkimos coastal where an inland ingressing parabolic dune complex was the critical environmental/geoheritage feature that resulted in strict management of the proposal (Environmental Protection Authority of Western Australia 2005); and 3. the Yalgorup National Park area where geoheritage values of the Holocene dune barrier, the Pleistocene limestones, and their groundwater system, and how they interfaced with the leeward lagoons resulted in a recommendation of no development or in strict management of any proposed future developments (Environmental Protection Authority of Western Australia 2010).

**Western Australian Planning Commission**

The Western Australian Planning Commission is a statutory authority of the Government of Western Australia with statewide responsibilities for urban, rural and regional land use planning and land development (Anon 2014d). Its main role is to coordinate the various government agencies and other stakeholders in large infrastructure projects, to ensure that consideration is given to all interests and needs, including environmental, economic and community interests.

An overarching guidance applicable to planning and landscape issues has been prepared by the Western Australian Planning Commission (WAPC) and includes State Planning Policy No. 2 *Environment and Natural Resources Policy* (Government of Western Australia 2003b). This State Policy requires that planning strategies, schemes and decision-making should identify and safeguard landscapes with high geological, geomorphological or ecological values, as well as those of aesthetic, cultural or historical value. Appreciation of natural and built environmental features that form part of the community’s heritage is considered to be an important cultural characteristic. The Western Australian Planning Commission considers Heritage places are of many types and may include geoheritage sites (e.g., where the Commission considers ‘geoheritage’ to be the natural geological features in the landscape and their cultural values). A ‘State geoheritage site’ is specifically recognised as one with geological features recognised by the Geological Survey of Western Australia (through the formal process of consideration by the State Geoheritage Committee as described earlier) as being of scientific importance – in this regard, the site of geoheritage significance has to be already recognised and listed by the Geological Survey of Western Australia and there is no scope or method for determining and protecting sites of geoheritage significance *a priori* or *de novo*.

The Western Australian Planning Commission also has a State Coastal Planning Policy, *viz.*, *State Planning Policy 2.6 State Coastal Planning*. The objectives of the State Coastal Planning Policy are to:

- ensure that the location of coastal facilities takes into account coastal processes, landform stability, coastal hazards, climate change and biophysical criteria;
- ensure the identification of appropriate areas for the sustainable use of the coast for housing, tourism, recreation, ocean access, maritime industry, commercial and other activities;
- provide for public coastal foreshore reserves and access to them on the coast;
- protect, conserve and enhance coastal zone values, particularly in areas of landscape, biodiversity and ecosystem integrity, indigenous and cultural significance; and
- make provision for the protection, conservation and enhancement in areas of landscape, nature, conservation, indigenous and cultural significance.
Section 8.4 of the State Coastal Planning Policy Guidelines defines Cultural Heritage to include knowledge, places and things, including those made or changed by humans, that have aesthetic, historic, scientific, social or spiritual significance or other special value for past, present and future generations. Stating that this generally relates to European heritage as Indigenous heritage is separately legislated. All levels of government are accountable for cultural heritage in Australia. Any identified culturally-significant coastal heritage sites should be incorporated into the coastal foreshore reserve with practical buffers and management to ensure protection of their values (WAPC 2013). However, there are no guidelines on what is “culturally significant” or what criteria will be applied.

**Department of Parks and Wildlife**

The current Department of Parks and Wildlife (DPAW), formerly known over the past 30 years (in succession) as the Department of Environment and Conservation, and the Department of Conservation and Land Management, has a mission in Western Australia to protect and conserve the State's natural environment on behalf of the people of Western Australia. It has primary responsibility for managing the State’s national parks, marine parks, State forests and other reserves, for conserving and protecting native animals and plants, and for managing many aspects of the access to and use of the state’s wildlife and natural areas.

While not directly stated in its policies and literature in managing national parks and other reserves and not part of its mission statement, DPAW has taken on a duty to ensure that the geology of an area, such as a National Park or Reserve, is not disturbed, that geological samples are not removed, and that some aspects of the geology of a park or reserve is described for visitors/tourists because disturbance of geology or removal of soils and abiotic samples are covered in its regulation forms for sampling. The fact is that visitors to national parks and reserves cannot take rock, sediment, soil, water, or biota without a formal permit and, if they do remove such material, they are in breach of law. But the protection of geological features in such instances is captured in this legislation only by default. In essence, DPAW has no formal policy in relation to geology, geoheritage and geoconservation. A review of the Department’s annual reports, Policy Statements, and Strategic Directions between 1990 and 2014 will find no mention of words ‘geology’, ‘geoheritage’ or ‘geoconservation’ (Department of Conservation & Land Management 1990; Department of Environment & Conservation 2012a, 2013; Department of Parks & Wildlife 2014a. 2014b). And, as highlighted earlier by Brocx (2008), as at 2014, DPAW (and earlier versions of this government agency) had/has no geologist on staff.

Though not addressing Geology, Geoheritage, or Geoconservation in Policy, Legislation and Planning, DPAW has been involved with promoting Geology in that it commissioned three booklets on the geology and landforms of National Parks and their regions, viz., the Kimberley region (Tyler 1996), the South-West region (Copp 2001), and the Pilbara region (Copp 2011).

DPAW is more directly involved in geology in its policy on caves and karst (Department of Parks & Wildlife 2014c), the focus of the policy being toward typical carbonate rock karst. The policy is directed toward caves/karst on land within the conservation estate (i.e., DPAW-protected land). Nonetheless, here DPAW has identified the importance of geology and the geological features of karst in limestone terrains. Using previous DPAW guidelines, and IUCN and EPA-WA criteria and guidelines (Watson et al. 1997; Environmental Protection Authority of Western Australia 2008a, 2008b) DPAW has published policies for the protection of the landforms, karst processes and speleothems. The policies for caves and karst are (Department of Parks & Wildlife 2014c):
1. to ensure that the reservation of representative karst is a consideration in establishing protected areas, and address the protection and management of karst values in the preparation of management plans;
2. to manage and protect karst on Conservation & Land Management Act land with special attention to the management of threatening processes, including those arising from water catchment processes;
3. to classify caves and manage public access to caves for recreation, tourism and other purposes, and to take a precautionary approach where any risk to speleothems, other karst values, Aboriginal heritage sites or human life may occur;
4. where possible and appropriate, to encourage and support the protection and management of karst outside Conservation & Land Management Act land through liaison, advice and promotion of best management practices and improved knowledge about the environmental significance of karst and its management;
5. to promote community awareness of, and appreciation for, caves and karst, including awareness of their special protection and management needs.
6. to arrange training and awareness programmes on karst management for department staff, volunteers and others involved in the planning and management of karst;
7. to review legislation and associated regulations on an ongoing basis in order to maintain or improve the protection and management of caves and karst on Conservation & Land Management Act land and other lands; and
8. to support research and monitoring of karst systems as required.

The Conservation & Land Management Act 1984 is the primary instrument for the protection and management of Conservation & Land Management Act land, including provisions for the preparation of statutory management plans. The Environmental Protection Act 1986 provides the mechanism through which land use, pollution and drainage impacts on karst values can be addressed through the assessment of proposals that may impact on karst features. The Wildlife Conservation Act 1950 provides state-wide protection of flora and fauna on all lands, including protection of stygofauna, troglofauna and 'dead fauna' which, in the context of karst, includes mummified fauna and bone material but not fully-fossilised fauna.

In this regard, although the Department of Parks & Wildlife (and earlier versions of this government agency) is a government body that deals with the triad of Nature, Conservation, and Parks, apart from caves and karst, it provides no information, direction, or strategy on how to manage geology, geoheritage, and geoconservation as part of the conservation estate.

**Policy and Legislation in relationship to wetland conservation in Western Australia – a case study of policy development for Geoheritage and Geoconservation**

The wetland conservation policies, wetland conservation, and legislation protecting wetlands were examined because they held potential to be used as a template on how to develop policies and how the policies and conservation strategies can be embedded in the government agencies. They also were examined because, as will be discussed below, the primary classification of wetlands in Western Australia was based on physical, geomorphic, and hydrologic attributes (and thus is close to being a focus on the ‘geological aspects’ of wetlands).
Progressive agencies in the Western Australian government (Water Authority of Western Australia, the Water & Rivers Commission, the Department of Environment & Conservation, and the Department of Parks & Wildlife), adopted the wetland classification of C A Semeniuk (1987) and (the expanded international version) of C A Semeniuk & Semeniuk (1995) published in the Atlas of the Wetlands of the Swan Coastal Plain (Hill et al. 1996). The classification of wetlands by C A Semeniuk (1987) was based on geomorphic and hydrologic attributes and so essentially emphasised the geologic features of wetlands as a basis for their fundamental categorisation. Initially, the classification was termed the “geomorphic” wetland classification (C A Semeniuk 1987), but to avoid confusion with the “hydrogeomorphic” classification that Brinson had developed (Brinson 1993, 2009), eventually the Western Australian classification was termed the geomorphic-hydrologic system (C A Semeniuk & Semeniuk 2011b). The term “geomorphic-hydrologic system” emphasised that the classification and the wetlands were geologic entities (as expressions of their geomorphic and hydrologic setting).

Subsequently, the Western Australian government agencies produced a series of policy documents in relationship to wetlands of the Swan Coastal Plain (Government of Western Australia 1997; Western Australian Planning Commission 2005; Anon 2006; Department of Environment and Conservation 2007, 2012b). These essentially are mission statements and guidelines on how to view and manage the wetland environment, assess the wetlands, and manage buffer zones around wetlands. They also provide policies, and outline legislation if wetlands are destroyed or impacted. Many of these policies address the geological/geomorphic settings of the wetlands.

To begin with, wetlands are protected by provisions under the Environmental Protection Act 1986 (the Act). Under this Act, an ‘alteration of the environment to its detriment or degradation or potential detriment or degradation’ or an ‘alteration of the environment to the detriment or potential detriment of an environmental value’ is considered environmental harm (Anon 2006). Such ‘harm’ would involve excavating, destroying stratigraphy, destroying or mining soils, or altering hydrogeology (in essence, the geological attributes of a wetland). The definition of environmental harm also specifically includes harm involving removal or destruction of, or damage to native vegetation or the habitat of native vegetation or indigenous aquatic or terrestrial animals.

Within this scope of protection, certain wetlands are defined as environmentally sensitive areas; these include:

1. Wetlands identified as internationally significant under the Ramsar Convention.
5. Wetlands mapped in “Mapping and Classification of Wetlands from Augusta to Walpole in the South West of Western Australia” (V & C Semeniuk Research Group 1997).
Other wetlands also listed as environmentally sensitive areas where exemptions do not apply include those areas covered by the:

1. Environmental Protection (Swan Coastal Plain Lakes) Policy 1992;
2. Environmental Protection (South West Agricultural Zone Wetlands) Policy 1998; and

Environmental Protection (Swan Coastal Plain Lakes) Policy 1992 protects the environmental values of selected wetlands on the Swan Coastal Plain. The policy prohibits the filling, excavating, mining, discharge or disposal of effluent into, and construction or alteration of a drainage system for the drainage into or out of an identified wetland, unless authorised under the Act or under any other written law. Effectively, this policy acting as legislation protects wetlands geologically in terms of geomorphology, sediments, soils, and hydrology. The Environmental Protection (South West Agricultural Zone Wetlands) Policy 1998 similarly prohibits filling, excavating, mining, discharging or disposal of effluent, damaging or clearing native vegetation, and construction or alteration of the water drainage system of protected wetlands, unless authorised under the Act or under any other written law. The Act includes penalties for breaches of the Law. The purpose of the Environmental Protection (Swan and Canning Rivers) Policy 1997 was to make provisions for the protection and enhancement of the ecological and community benefits and amenity of the Swan and Canning Rivers and associated lands. The new Swan and Canning Rivers Management Bill 2005 replaced the Swan River Trust Act 1988 and the Environmental Protection (Swan and Canning Rivers) Policy 1997. The new legislation improves the State's ability to coordinate management of activities that may affect the Swan and Canning Rivers.

Development proposals that are likely to have a significant impact on a wetland of high conservation significance, such as a conservation category wetland, is considered to be a major under s38 of the Environmental Protection Act 1986 and needs to be referred to the Environmental Protection Authority (EPA-WA). Development proposals that may affect wetlands protected by the Environmental Protection (Swan Coastal Plain Lakes) Policy 1992 or by the South West Agricultural Zone Wetlands also require referral to the EPA-WA. In these contexts, wetlands, and their geological attributes, are considered significant and are protected by Law.

In terms of policy and legislation, the Department of Parks and Wildlife, the Department of Environment and Conservation, the Water & Rivers Commission, and the Water Authority of Western Australia over time have serially published or provided policies that related to the protection and management of wetlands. They also drafted or used existing key existing legislation which protected wetlands. These documents, policies, legislation and Acts are listed in Tables 11.2 and 11.3. Particularly interesting is the range of policy documents (29 in total) that directly or indirectly deal with wetland protection and management.
**Table 11.2: Key policies for wetland management and protection (Department of Environment and Conservation 2012b)**

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<td>1.</td>
<td>Wetlands Conservation Policy for Western Australia; Government of Western Australia, 1997.</td>
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<td>2.</td>
<td>Draft Guideline for the Determination of Wetland Buffer Requirements; Western Australian Planning Commission 2005,</td>
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<td>3.</td>
<td>WA Environmental Offsets Policy, Government of Western Australia, 2011</td>
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<td>4.</td>
<td>Environmental Protection (Swan Coastal Plain Lakes) Policy 1992; Government of Western Australia, 1992</td>
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<td>5.</td>
<td>Environmental Protection (South West Agricultural Zone Wetlands) Policy 1998 // Govt. of WA // 1998</td>
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<td>6.</td>
<td>Environmental Protection (Western Swamp Tortoise Habitat) Policy 2011; Government of Western Australia, 2011</td>
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<td>7.</td>
<td>EPA Position Statement No 4 Environmental Protection of Wetlands; Environmental Protection Authority 2004</td>
</tr>
<tr>
<td>8.</td>
<td>EPA Guidance Statement No 7 Protection of the Western Swamp Tortoise Habitat, Upper Swan/Bullsbrook; Environmental Protection Authority 2006</td>
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<tr>
<td>9.</td>
<td>EPA Position Statement No 9 Environmental Offsets; Environmental Protection Authority 2006</td>
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<td>10.</td>
<td>EPA Guidance Statement No 10 Levels of assessment for proposals; Environmental Protection Authority 2006</td>
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<td>11.</td>
<td>EPA Guidance Statement No 19 Environmental offsets; Environmental Protection Authority, 2008</td>
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<td>12.</td>
<td>EPA Guidance Statement No 28 Protection of Lake Clifton catchment; Environmental Protection Authority, 1998</td>
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<td>13.</td>
<td>EPA Guidance Statement No 33 Environmental guidance for planning and development; Environmental Protection Authority, 2008</td>
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<td>15.</td>
<td>State Planning Policy 2 Environment and natural resources policy; Western Australian Planning Commission, 2003</td>
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<td>16.</td>
<td>State Planning Policy 2.1 Peel-Harvey coastal plain catchment; Western Australian Planning Commission, 1992</td>
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<td>17.</td>
<td>State Planning Policy 2.2 Gnangara groundwater protection; Western Australian Planning Commission, 2005</td>
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<td>18.</td>
<td>State Planning Policy 2.3 Jandakot groundwater protection; Western Australian Planning Commission, 1998</td>
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<td>19.</td>
<td>State Planning Policy 2.8 Bushland Policy for the Perth Metropolitan Region; Western Australian Planning Commission, 2005</td>
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<td>20.</td>
<td>State Planning Policy 2.9 Water resources; Western Australian Planning Commission, 2006</td>
</tr>
<tr>
<td>22.</td>
<td>Acid sulfate soils planning guidelines; Western Australian Planning Commission, 2008</td>
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<tr>
<td>23.</td>
<td>Policy framework for inland drainage; Department of Water, 2012</td>
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<tr>
<td>24.</td>
<td>Better Urban Water Management Strategy; Western Australian Planning Commission,</td>
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<tr>
<td>26.</td>
<td>Water allocation planning in Western Australia: a guide to our process; Department of Water, 2011</td>
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<td>28.</td>
<td>Decision process for stormwater management in WA; Department of Water, 2009</td>
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Table 11.3: Key Acts for direct and indirect wetland management and protection (Department of Environment and Conservation 2012b)

<table>
<thead>
<tr>
<th>Acts and Statutes</th>
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<tr>
<td>Environmental Protection Act 1986</td>
<td>Function of the Environmental Protection Authority (Part II)</td>
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<td>• Development of policies for environmental protection (Part III)</td>
<td>• Environmental impact assessment (Part IV)</td>
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<tr>
<td>• Regulation of pollution, environmental harm and clearing (Part V);</td>
<td>Department of Environment and Conservation (Part V)</td>
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<tr>
<td>Wildlife Conservation Act 1950</td>
<td>Protection of native flora and fauna; Department of Environment</td>
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<td>Conservation and Land Management Act 1984; Use, protection, and management of</td>
<td>and Conservation</td>
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<td>certain public land and waters; Department of Environment and Conservation,</td>
<td>Conservation Commission</td>
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<tr>
<td>Planning and Development Act 2005</td>
<td>State planning policies</td>
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<td>• Region planning schemes</td>
<td>• Local planning schemes</td>
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<tr>
<td>• Subdivision and development control; Western Australian Planning Commission,</td>
<td>Department of Planning, Local government</td>
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<tr>
<td>Conservation Commission</td>
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<tr>
<td>Aboriginal Heritage Act 1972; Conservation of and protection for places and</td>
<td>Aboriginal people; Department of Indigenous Affairs</td>
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<td>objects of importance to Aboriginal people;</td>
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<tr>
<td>Fish Resources Management Act 1994; Protection of aquatic species and habitats;</td>
<td>Department of Fisheries</td>
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<tr>
<td>Rights in Water and Irrigation Act 1914; Some protection of water resources in</td>
<td>Department of Water</td>
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<td>proclaimed areas. Assigns rights to take water from the environment.</td>
<td>Soil and Land Conservation Commission</td>
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<tr>
<td>Soil and Land Conservation Act 1945; Protection of land degradation (erosion,</td>
<td>Department of Regional Development and Lands</td>
</tr>
<tr>
<td>salinity and flooding) which may impact wetland condition;</td>
<td>Management of pastoral lands;Pastoral Lands Board (through the</td>
</tr>
<tr>
<td>Land Administration Act 1997; Management of pastoral lands;</td>
<td>Department of Environmental and Conservation, Conservation</td>
</tr>
<tr>
<td>Commonwealth Acts</td>
<td>Commission</td>
</tr>
<tr>
<td>Environment Protection and Biodiversity Conservation Act 1999</td>
<td>• Protection and manage matters of national environmental</td>
</tr>
<tr>
<td>• Regulations outlining the Australian Ramsar management principles; Department</td>
<td>significance</td>
</tr>
<tr>
<td>of Sustainability, Environment, Water, Population and Communities</td>
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Unlike other States in Australia and other Nations worldwide (Brinson 1993, 2009), in Western Australia, it is clear that there is a plethora of policy and legislation to protect and manage wetlands, and that wetland conservation and management is not solely about biology but seeks to conserve and manage their geological aspects.

However, while today there is legislation and policy to protect and manage wetlands, the evolution of these policies and legislation was not systematic. It advanced ad hoc as needs arose, and evolved as more precise scientific information and understanding of wetland functioning became available. In this context, for the benefit of Geoheritage and Geoconservation, and particularly for coastal geoheritage, the various individual policies and legislation may be of use if adapted for coastal geoheritage, but the Western Australian model of these processes and instruments as they unfolded historically for wetlands has no direct applicability to Geoheritage, Geoconservation, and management and protection of coastal geoheritage.
Policy and Legislation for Geoheritage and Geoconservation in the coastal zone
There is no focus or emphasis on coastal geoheritage neither in any State of Australia nor Federally in Australia. Therefore, there is no literature, policies, or guidelines on the subject, even though some of the best outcrops of geology are coastal exposures. The concept of ‘coastal geoheritage’ and its importance within the realm of geoheritage generally has not been explored or identified except by Brocx & Semeniuk (2009a) and in this Thesis.

Discussion - What principles from National and State policies can be used in developing policy for protecting sites of significance in coastal geoheritage in Western Australia
In Australia, there has been some progress made within the States in relation to heritage legislation and defining concepts of what constitutes sites of geoheritage significance, and in identifying and preserving such sites, particularly in Tasmania. In Western Australia, however, no such initiatives are being undertaken and no legislation exists for the conservation of the majority of sites of geoheritage significance. In pursuing geoconservation, individual States have made effort, through the advice of their governmental and university geologists, to preserve geological monuments and palaeontological and stratigraphic type locations and type sections, enormous effort by a number of individuals working towards identification and preservation of sites considered to be geological monuments (Brocx 2008). In this regard, Tasmania has made progress through the work of Kiernan (1990, 1997) and Pemberton (2001) and South Australia has an extensive list and map of geosites. Through their efforts, in Tasmania and South Australia, there has been a large range of landforms and geological features preserved as sites of geoheritage significance.

While some of the geoconservation initiatives outlined above at the Federal and State level within Australia have been worthwhile and significant in that sites of Geoheritage significance have been identified and suggested for preservation, in contrast to the European experience there still are large deficiencies and gaps in the conceptualisation of the issues and in the process of their preservation and management. The criteria presented in Table 11.1 for identifying sites of Geoheritage significance Australia-wide proffered by the Federal Department of the Environment were not wholly comprehensive and not robust in 2007 (Brocx 2008) and are still not now. They are nowhere nearly exhaustive and robust as the criteria set out in Tables 10.3, 10.4, 10.5, 10.6 & 10.7 by the United Kingdom and the United States of America, or that underpinning the selections of RIGS, as well as the GCR criteria and guidelines, and do not adequately address identification of sites of geoheritage significance as does the Geoheritage Tool-kit described earlier in this Thesis. For geoheritage issues there was no emphasis on type locations, type sections, teaching locations, classic locations (i.e., well-known published sites), and outstanding monuments (e.g., important crystal locations, or structural geological features, amongst many others; cf. Brocx & Semeniuk 2007). Further, there is no classification or grading of sites as provided in the United Kingdom as shown in Tables 10.3, 10.4 & 10.5. With the dismantling of the Register of National Estate, and a move to the thematic approach (which is a limited approach), the large list of former RNE sites are not protected and the evolving new list that is yet to be completed will vastly under-represent the diversity of Australia’s geoheritage.

At the Australian Federal level, the Department of the Environment largely has downgraded the importance of geoheritage and geoconservation, and has ignored an august and learned body such as the Geological Society of Australia in its recent (2014) deliberations on defining its Heritage Strategy (Department of Environment 2015). For a government agency that has the role of managing the heritage of Australia, the Department of the Environment, in addressing a large, diverse, and unique continent such as Australia, has done very little in the field of Geoheritage and Geoconservation. It has not even continued nor built on the work of the 1970s-1990s carried out by the Australian Heritage Commission and the former Australian Nature Conservation Agency.
As noted earlier, at the National level, Department of the Environment (and most of its predecessors) provides no useful models for Policy and Legislation for Geoheritage and Geoconservation.

Many of the agencies and NGOs at national and State in Australia, while they deal with some aspect of Geoheritage and Geoconservation, do not strictly and robustly address issues of geoheritage.

The exception is the Geological Society of Australia. This nation-wide NGO for geology has a Geoheritage policy. It is a fairly thorough national policy that could/should be adopted nationally for Geoheritage and Geoconservation. It would be particularly powerful and robust if the criteria for selection of sites and rationality for selection of sites such as presented in Tables 10.3, 10.4, 10.5, 10.6 & 10.7 were incorporated into the policy.

In Western Australia, the agencies for the environment and conservation do little in the arena of Geoheritage and Geoconservation and, as such, there are no policies that are useful. The Environmental Protection Authority of Western Australia, on the other hand, had addressed Geoheritage and Geoconservation in a number of its Policy Statements and its assessment reports. In fact, the Environmental Protection Authority of Western Australia, as a government agency, has been a champion of Geoheritage and Geoconservation in the State.

There are State-wide policies and legislation for wetlands in Western Australia and while they function for the management and protection of wetlands, their wording, philosophy, and scope are definitively oriented towards wetlands. They do show the policies and legislation can be adapted for Geoheritage and Geoconservation. Similarly, there are State-wide policies and legislation for karst in Western Australia and they too function for the management and protection of karst features, however, their wording, philosophy, and scope also can be adapted to Geoheritage and Geoconservation.

Given that globally and in Australia coastal geoheritage has not been identified as a heritage endeavour, there has been no development of policies and legislation to address what needs to be conserved, what details are required in procedure to protect coastal sites, and what details are required in procedure to protect people. As such, development of Policy and Legislation in this arena is an entirely new field of endeavour and will be the subject matter of the next Chapter.
Chapter 12: Policy and Legislation in relationship to Geoheritage and Geoconservation

- Matters to be considered in the design of a coastal geoheritage policy

As outlined in Chapter 4, the coast is one of the most complex environments on the Earth’s surface, being a zone of intersection and interaction of land, sea, groundwater, and atmosphere and the processes therein, and carries processes and products that are either not present or only weakly developed elsewhere. With other matters such as lithology, structure, or geological framework being equal, the coastal zone is one that generally results in greater geodiversity (*i.e.*, varied assemblage of geological features) than elsewhere. As with other environments, the complexity and geodiversity developed along the coast are variable according to parent rock types, sediments, and other materials, biodiversity, hydrochemical effects, diagenesis, and variable according to environmental setting and climate. Brocx and Semeniuk (2008) developed a category-based method for identifying sites of geoheritage at all scales, and all levels of significance, *i.e.*, from international to local significance. Addressing the full gamut of what constitutes Geology and Geoheritage is particularly important when a given site or area has inter-related or interacting aspects of geological features. This is especially relevant for sites of geoheritage significance in modern settings such as the coast. If in such settings the focus, for instance, is only on geological products (such a gypsum precipitates, or dolomite precipitates, or calcrite formation), then the framework and processes leading to the development of these products will not be captured as being of geoheritage significance. Diagenesis and the precipitation of diagenetic minerals or the diagenetic alteration of pre-existing materials in a Holocene setting where there are stratigraphic, hydrological, and hydrochemical gradients is an example. Focusing only on the mineral products underestimates the full scope of geoheritage features, misses the importance of the story of the inter-related aspects of a stratigraphy, hydrological dynamics, and hydrochemistry that led to the precipitation of the mineral products, and may overlook the maintenance processes whereby hydrological dynamics, and hydrochemistry in a stratigraphic context drive diagenesis and the development of the different diagenetic products along a environmental gradient. The maintenance processes that underpin products of geoheritage significance are also significant in their own right but, additionally, loom as important in developing geo-management strategies to protect the significant features.

The freshwater seepage along the dune margin of the Leschenault Peninsula and the hydrochemical gradient along the tidal flats of Shark Bay exemplify this (Cresswell 2000; Brocx & Semeniuk 2011a; Logan 1974). For the former, the ensemble of stratigraphy, hydrology, and hydrochemistry provides the modern geological framework and the processes therein that result in the precipitation of carbonate minerals such as calcite, Mg-calcite, and dolomite as nodules, platelets, and rhizocretions along the interface of the barrier dune and estuary. For the latter, the modern geological framework and the processes therein result in the precipitation of carbonate minerals such as calcite, Mg-calcite, and aragonite as pore-filling cements, and gypsum as isolated crystals, pore-filling clusters, and rosettes along the gradient of hypersalinity in the groundwaters of the tidal flats.

Currently, in Australia, and globally, while there is significant evidence of recognition of the importance of geoheritage beginning with the International Declaration of the Rights of the Memory of the Earth (Martini 1993), the establishment of an international journal, Geoheritage, (since 2009) and more recently, the inclusion of Geoheritage within the IUCN World Commission on Protected Areas Programme 2013-2016 (IUCN 2008), there are no direct or indirect legislative or policy tools that address the range and scope of geoheritage, let alone Coastal geoheritage as an important endeavor in its own right.
Prior to designing policy for coastal sites of geoheritage significance in Western Australia, this Chapter deals with matters that need to be considered. The structure of this Chapter is as follows:

1. Introduction – why Policy is needed for protecting sites of significance in coastal geoheritage.
2. The steps required to identify and manage sites of geoheritage significance – the 8Gs.
3. The issue of safety and accessibility in coastal geoheritage sites.
4. The issue of protecting fragile or vulnerable coastal geoheritage sites.
5. Science and Education at a coastal geoheritage site

**Why Policy is needed for protecting sites of geoheritage significance in coastal geoheritage and protecting people from coastal dangers**

Coastal sites of geoheritage significance in many ways are no different to other types of sites of geoheritage significance in that they are geological legacies as reference sites, classic sites for geological principles, cultural sites, geohistorical sites, and sites illustrating active processes, and they require geoconservation at various levels of security depending on their significance. Coastal sites of geoheritage significance require policy as would non-coastal sites of geoheritage significance; however, as outlined in the introduction to this Chapter, coastal geoheritage presents another set of environmental factors that need special management that sets coastal sites apart from terrestrial (inland sites). For instance, coastal areas can be notoriously dangerous for people. This relates to issues of accessibility, cliff collapse, people falling from (high) cliffs, people falling as a result of crumbling edges of cliffs or collapsing cliffs, and the dangers of tides, waves, and ‘king waves’. All of these pose safety issues that need addressing if sites of coastal heritage significance are to function for education, research, and tours.

Thus, beyond the issues of policy development for protecting sites of significance in coastal geoheritage that relates directly to the protection of the site itself from a scientific perspective, coastal policy needs to be integrated with a management component for the safety of people who access these sites such as school children (e.g., on excursions), uninformed foreign tourists, higher-level Tertiary education students (e.g., on University excursions), community group personnel, amateur naturalists, and researchers.

**The basis of policy - from Geology, through to Geoheritage, to the establishment and management of Geosites/Geoparks, leading to Geo-education and Geotourism**

The basis of policy is embodied in the concept of the “8Gs”, *i.e.*, the progression from Geology to Geo-education, and Geotourism (Brocx 2014).

Essentially, the key aspects deriving from the study, protection, management and education in the field of Geology, can be summarised as the “8Gs”, *i.e.*, (1) Geology itself, (2) Geodiversity, (3) Geoheritage, (4) Geoconservation, (5) Geosites/Geoparks, (6) Geo-management, (7) Geo-education, and (8) Geotourism. In this Thesis, the aspects of the 8Gs will be Geoheritage, Geoconservation, Geosites/Geoparks, Geo-management, and to a limited extent, Geo-education – the full scope of Geo-education and the matters of Geodiversity are outside the scope of this Thesis.

The growing field of geoheritage, geo-education and geotourism globally, and Nationally in Australia, has led to a need to better define the terms associated with these endeavours in the body text of any policy and legislation, develop concepts and procedures to deal with them, and understand the need to manage sensitive geological sites and areas of geoheritage significance.
Frequently there is confusion, misunderstanding, and misrepresentations in reports, discussions, and some papers as to what comprises geoheritage, geodiversity, geoconservation, as to what are the differences between geoheritage and geodiversity, and how these relate to land management and geotourism. While the definitions of geoheritage, geodiversity, and geoconservation have been presented in Chapter 2, this Chapter will elaborate further on the concepts underlying these notions and endeavours, and will discuss how Geoheritage is related to Geo-education and Geotourism.

**Geology** has a dual meaning – *Geology* is the discipline of the study of the Earth. It is also the term used to denote all features that are abiotic materials of specific areas of the Earth (namely, the structure, rocks, sediments, soils, groundwater, landforms, and the innumerable processes that operate and form and modify the materials of the Earth). In the latter context, it can be used to refer to the ‘geology of the Kimberley Region, or the ‘geology of the Pilbara Region’.

**Geodiversity** refers to the diversity of geological features in a given area or, for some authors, the diversity of geology itself. The former definition is preferred in this Thesis (Chapter 2). A given region/area may be of low geological diversity, consisting of a monotonous sequence, hundreds of metres thick, of a structurally simple, relatively uniform lithology such as quartz sandstone. Or, on the other hand, it may have high geodiversity with a plethora of lithologies, their weathered products, faults and fractures, structures such as folds, and a variety of mineral species and, within its sedimentary sequences, contain a rich diversity of fossils crossing various geological periods, amongst other geological features. This latter type of site thus may be an ideal location for the teaching of the components and principles of Geology.

The definition of **Geoheritage** is re-iterated here because it is important to clearly separate the notion of **Geoheritage** from **Geoconservation** and **Geotourism**, and important that land managers, Parks managers, Policy makers, and Geotour operators understand its meaning. At present, for instance, many geotourism operators confuse geoheritage and geotourism, and Parks managers and land managers similarly confuse and mix the two. As such, sites of geoheritage significance may become degraded through overuse or through over-collecting because, in being used for geotours geotourism, operators often hold the belief that geoheritage sites are equivalent to geotour sites. Fossil sites that are over-collected as part of geotours and degradation of outcrops by trampling and hammering during tours stand as examples where unmanaged geotourism can affect sites of geoheritage significance.

As noted in Chapter 2, **Geoheritage** is the legacy of geological features. It is the endeavour that seeks to evaluate and recognise the features of significance of the Earth, through a process of identification-categorisation-and-evaluation, ultimately for their preservation for heritage values, research, education, and tourism. Also, there can be many levels of significance allocated to different sites of geoheritage significance – sites that are of the highest level of significance need the highest level of protection and may be prohibited from use as sites for geotours.

While Geoheritage addresses the value and significance of geological features, **Geoconservation** seeks their preservation through various land-use instrumentalities and Laws (Brocx & Semeniuk 2007).

Identification of a site or sites of geoheritage significance may require the site/sites to be inscribed as an area of conservation as a **Geosite** (also referred to in the United Kingdom as Sites of Special Scientific Interest, or SSSI; see Chapter 10), or as an ensemble of sites in a **Geopark** (sensu Brocx & Semeniuk 2011a). Once the value of a geological feature that has been assessed as being of geoheritage significance and identified as a geosite or geopark, prior to its use as a site for Education, Reference, Research, or Tourism, its physical/chemical vulnerability and its ability to sustain frequent visitors and/or collecting, or its risk as a hazard has to be ascertained, and management plans need to be designed. This is the matter of **Geo-management** and needs to be pursued prior to any use of the
site(s) of geoheritage significance for Geo-education and Geotourism to ensure that the latter endeavours do not degrade or diminish the site though indiscriminate trampling, collecting, or anthropogenically-induced changes to the environment (e.g., caves; cf. Fernández-Cortés et al. 2006), and that the matter of safety is addressed. Figures 12.1, 12.2 & 12.3 illustrate some of the issues that relate to geo-management.

*Geo-education* is the use of sites by Primary, Secondary and Tertiary teaching institutions, and amateur geological organisations, for the purposes for imparting geological information to students, amateur geologists, and naturalists from the site (Figure 12.4). Figure 12.5 illustrates the style of geo-management and geo-education at Hallett Cove Conservation Park.

*Geotourism* involves the responsible supervised, unsupervised, brochure- and/or booklet-directed, or billboard-directed activities (or mobile phone portals for accessing descriptions of geotourist sites, e.g., GeoTreat™), all for the purpose of imparting geological information to local, National, and International visitors. As noted earlier, activities of Geo-education and Geotourism run risks of degrading any Geosites or Geoparks of significance and, hence, prior to any use of a given Geosite or Geopark for use in Geo-education and Geotourism, there needs to be management assessment and design/publication of geo-management plans – otherwise sites of International or National significance can/will become degraded. Figure 12.5 illustrates an ideal location for geotourism and implementation of geo-management at Hallett Cove Conservation Park where there are board-walks to direct the tourists (thus controlling indiscriminate walking), observation platforms and look-outs from which to appreciate the iconic views, and information boards to explain the geology.

*Geodiversity*, as the diversity of geological features in a given area, is outside the sequence outlined above. Geodiversity is linked to, and underpins Biodiversity (Semeniuk 1996a). In Geo-education and Geotourism, where educationalists and tour operators seek to demonstrate the link between ecosystems and geology (i.e., ‘Geodiversity underpins Biodiversity’), management plans are needed for ecosystems as well as for geological systems.

Thus, in the field of Geoheritage and Geoconservation leading to Geo-education and Geotourism, ideally, there should be seven steps that are sequential, summarised as follows: Geology, Geoheritage, Geoconservation, Geosites/Geoparks, Geo-management, Geo-education, and Geotourism. Geodiversity is brought in as a separate endeavour as a template to understanding and managing the biodiversity of a region or locality. These concepts are diagrammatically illustrated in Figure 12.6.

**The issue of safety and accessibility in coastal geoheritage sites**

Coastal areas can be inherently dangerous to visitors, geotourists, researchers, and students if not approached with knowledge. Rocky shores, for instance, though providing cliffs with excellent outcrops of stratigraphy and other geological features, manifest access problems because often the descent down the cliff will be steep and difficult. There will be safety problems because of the risk of personnel falling from cliff edges or from crumbling cliff edges or from steep slopes, the risk of rock falls (in recent years, in 1996, for instance, the cliff collapse along a limestone rocky shore in Gracetown, south-western Australia resulted the death of five adults and four children; Gordon 1999), and the risk of slippery surfaces in tidally-exposed zones where rocks are covered in a film of alga. There will also be safety issues where large boulders, strewn along the foot and lower part of a cliff, form unstable surfaces for walking. Rocky shores often are locations where waves are attenuated because of steep near-shore coastal gradients. Waves also are reflected back from the rocky coast into the incoming (shoreward-moving) wave sets, augmenting them and producing chaotic wave fields – as a result, there may be unpredictable ‘king waves’ and unexpected higher-than-normal waves that can wash people off the shore platforms. Macrotidal coasts present another type of danger because of the rapidity with which a rising tide can flood a rocky shore, particularly on a spring tide. And following
rain or high tides, rock cliffs with a shale or clay component may become unstable and be involved in landslides. Additionally for Australia, rocky shores and specifically shore platforms in tropical areas support venomous biota such as the blue-ringed octopus, stone fish, and cone shells, all of which can induce painful or even lethal stings. These matters of the dangers of the biota along the coast, although biological, have relevance to geoheritage in that these dangers need to be addressed in management plans for geosites for the safety of visitors.

At the other extreme, with sedimentary shores, there may be a different range of situations dangerous to visitors, geotourists, researchers, and students. These include rips that unexpectedly occur and involve collapse of sandy beaches in their high-tidal or dry supratidal parts, macrotides with swift currents that can rapidly invade muddy tidal flats, deep and thixotropic mud where people can sink and be immobilised (this is particularly dangerous if compounded by a rapidly rising spring tide), and dangerous predatory biota such as sharks and crocodiles that inhabit coastal zones.

Safety issues or hazards peculiar to the coastal zone in Western Australia are listed in Table 12.1.

More specifically, a selected range of safety issues or hazards that needs to be addressed for the different types of rocks shores (high sandstone cliffs, bouldery shores, high limestone cliffs, shaley shores, faulted rocks), sandy beach shores, tidal flats, and estuaries in macrotidal, and in wave-dominated, or in rip-dominated coastal zones is outlined in Table 12.2. The full range of possible rock types along rocky shores, as manifest in lithology, structural attitude, and microstructural features, represented elsewhere globally is not present in Western Australia and, accordingly, Table 12.2 presents a limited range of rocky shore types lithologically.

The Western Australian coast tends to be macrotidal in the tropical climates wherein there is a diverse dangerous biota that includes crocodiles, cone shells, and stone fish and, if wading in shallow water, the potential of encountering venomous jelly fish and inshore predatory sharks. The coast tends to be microtidal in the subtropical and temperate climates of Western Australia and therein it has a less diverse dangerous biota which does not pose the same dangers; the biggest risk when wading is the rare encounter with inshore hunting sharks or with stingrays.
Table 12.1: Safety issues or hazards peculiar to the coastal zone in Western Australia separated into categories of geomorphology, lithology, biota, and coastal processes

<table>
<thead>
<tr>
<th>Geomorphology</th>
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<tbody>
<tr>
<td>Sheer cliffs and bluffs</td>
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<tr>
<td>Steep cliffs</td>
</tr>
<tr>
<td>Very steep slopes</td>
</tr>
<tr>
<td>Crumbling cliffs</td>
</tr>
<tr>
<td>Undercut cliffs</td>
</tr>
<tr>
<td>Collapsing cliffs</td>
</tr>
<tr>
<td>Rugged cliffs</td>
</tr>
<tr>
<td>Difficult-to-traverse slopes</td>
</tr>
<tr>
<td>Slippery slopes</td>
</tr>
<tr>
<td>Pinnacles and lapiés</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Lithology</th>
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</thead>
<tbody>
<tr>
<td>Sandstone cliff collapse to form block-and-boulder shore</td>
</tr>
<tr>
<td>Limestone cliff collapse to form block-and-boulder shore</td>
</tr>
<tr>
<td>Inundated terrestrial scree to form block-and-boulder shore</td>
</tr>
<tr>
<td>Slippery shale rocks</td>
</tr>
<tr>
<td>Thixotropic tidal-flat sand</td>
</tr>
<tr>
<td>Thixotropic tidal-flat deep mud</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Biota</th>
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</thead>
<tbody>
<tr>
<td>Slippery algal film on low tidal rocks</td>
</tr>
<tr>
<td>Stonefish in rocky-shore pools</td>
</tr>
<tr>
<td>Crocodiles</td>
</tr>
<tr>
<td>Sharks venturing into shallow water</td>
</tr>
<tr>
<td>Cone shells</td>
</tr>
<tr>
<td>Blue-ringeed octopus</td>
</tr>
<tr>
<td>Jellyfish in shallow water</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Coastal processes</th>
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</thead>
<tbody>
<tr>
<td>Rising high tide in a macrotidal setting</td>
</tr>
<tr>
<td>Breaking swell and its undertow on the beach</td>
</tr>
<tr>
<td>Long-shore currents</td>
</tr>
<tr>
<td>Rip currents</td>
</tr>
</tbody>
</table>

Visitors to sites of geoheritage significance need to be made aware of all the dangers noted above that are peculiar/specific to a given site. In addition, land managers and government agencies responsible for the site need to manage the site (e.g., construct safe walkways). Clearly, to protect people when they are visiting a site of geoheritage significance, a safety management programme needs to be designed bearing in mind the type of hazards listed above.
<table>
<thead>
<tr>
<th>Type of coast</th>
<th>Nature of the shore</th>
<th>Key issues for safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macrotidal rocky coast (tide-dominated rocky coast)</td>
<td>High cliffs descending vertically or very steeply, or stepped; strewn with blocks and boulders on lower slopes; often with subhorizontal or stepped platform at low tide level; mid-to low-tidal surfaces can be covered in oysters and barnacles</td>
<td>Dangerous access down steep or vertical cliffs; slippery or rubble slopes; loose and falling blocks; lower cliffs, slopes, and platforms subject to freak high waves, ‘king waves’, and/or rapid inundation on a rising tide; low-tidal platforms slippery with algae, and pools inhabited by blue-ringed octopus and stonefish; falling on oyster/barnacle-covered surfaces can result in severe lacerations</td>
</tr>
<tr>
<td>High sandstone cliff (e.g., Kimberley Coast)</td>
<td>High cliffs descending vertically or very steeply, or stepped; strewn with blocks and boulders on lower slopes; often with subhorizontal or stepped platform at low tide level; mid-to low-tidal surfaces can be covered in oysters and barnacles</td>
<td>Dangerous access down steep or vertical cliffs; slippery or rubble low-tidal slopes; loose and falling blocks; lower cliffs, slopes, and platforms subject to freak high waves, ‘king waves’, and/or rapid inundation on a rising tide; rock platforms are slippery with algae, and pools are inhabited by blue-ringed octopus and stonefish; falling on oyster/barnacle surfaces can result in severe lacerations</td>
</tr>
<tr>
<td>High limestone cliff (e.g., west coast Dampier Peninsula, Canning Coast)</td>
<td>High cliffs descending vertically or very steeply; strewn with blocks and boulders on lower slopes; often with benches; subhorizontal or stepped platform at low-tide level; limestone surfaces commonly micro-pinnacled; Pleistocene limestone tends to be well indurated, Holocene limestones tend to be friable; mid-to low-tidal surfaces can be covered in oysters and barnacles</td>
<td>Dangerous access down steep or vertical cliffs and on rubble low-tidal slopes; loose and falling blocks; lower cliffs, slopes, and platforms subject to freak high waves, ‘king waves’, and/or rapid inundation on a rising tide; rock platforms are slippery with algae, and pools are inhabited by blue-ringed octopus and stonefish; falling on oyster/barnacle-covered surfaces can result in severe lacerations</td>
</tr>
<tr>
<td>Rugged igneous rock high cliff (e.g., granitic and mafic rocks of the Dampier Archipelago, Pilbara Coast)</td>
<td>Cliffs descending vertically or very steeply; strewn with blocks and boulders on lower slopes; mid-to low-tidal surfaces can be covered in oysters and barnacles</td>
<td>Dangerous access down steep or vertical cliffs; slippery slopes; lower cliffs/slopes, and platforms subject to high waves, ‘king’ waves, and/or rapid inundation on a rising tide; low-tidal areas slippery with algae, and pools inhabited by blue-ringed octopus and stonefish; falling on oyster/barnacle surfaces can result in severe lacerations</td>
</tr>
<tr>
<td>Rugged sandstone low cliff (e.g., Kimberley Coast)</td>
<td>Low-relief cliffs descending vertically or very steeply, or stepped; strewn with blocks and boulders on lower slopes; often with subhorizontal or stepped platform at low tide level; mid-to low-tidal surfaces can be covered in oysters and barnacles</td>
<td>As above for high sandstone cliffs</td>
</tr>
</tbody>
</table>
| **Rugged limestone low cliff**  
  *(e.g., Port Hedland)* | **Low-relief cliffs descending vertically or very steeply; often with benches; subhorizontal or stepped platform at low tide level; limestone surfaces commonly micro-pinnacled; mid to low-tidal surfaces can be covered in oysters and barnacles** | **As above for high limestone cliffs** |
|---|---|---|
| **Shaley shores**  
  *(e.g., Pilbara Coast)* | **Cliffs descending vertically or very steeply, or stepped; surface often splintery and friable shaley** | **As above for high sandstone cliff but with added risk from splintery and crumbling shaley** |
| **Basalt shores**  
  *(e.g., Kimberley Coast and Pilbara Coast)* | **Cliffs descending vertically or very steeply; strewn with blocks and boulders on lower slopes; mid- to low-tidal surfaces covered in oysters and barnacles** | **As above for high sandstone cliff** |
| **Faulted rock**  
  *(e.g., Kimberley Coast and Pilbara Coast)* | **Cliffs descending vertically or very steeply; surface often splintery and friable rock due to shear zones, fracture zones, and fault-rock** | **As above for high sandstone cliff but with added risk from splintery and crumbling shear zones, fracture zones, and fault rock** |
| **Bouldery shores**  
  *(e.g., Dampier Archipelago, Pilbara Coast)* | **Moderately inclined shore underlain by boulders and blocks, with vertical cliff in upper tidal and supratidal zones; mid- to low-tidal surfaces covered in oysters and barnacles** | **As above for high sandstone cliff but with added risk from abundant unstable surfaces of boulder and block aggregate** |
| **Microtidal wave-dominated rocky coast; microtidal wave- and rip-dominated rocky coast** | **High sandstone cliff**  
  *(e.g., Red Bluff, Kalbarri)*  
  **High cliffs descending vertically or very steeply, or stepped; strewn with blocks and boulders on lower slopes; often with subhorizontal or stepped platform at low tide level**  
  **Dangerous access down steep or vertical cliffs; loose and falling blocks; lower cliffs, slopes, and platforms subject to freak high waves, or ‘king’ waves; low-tidal platforms slippery with algae** |
| **High limestone cliff**  
  *(e.g., Zuytdorp Coast)*  
  **High cliffs descending vertically or very steeply, or stepped; often with subhorizontal or stepped platform at low tide level**  
  **Dangerous access down steep or vertical cliffs; loose and falling blocks; lower cliffs, slopes, and platforms subject to freak high waves, or ‘king’ waves; low-tidal platforms slippery with algae** |
| **Rugged limestone low cliff**  
  *(e.g., Muderup Rocks)*  
  **Cliffs descending vertically or very steeply, or stepped with benches; often with subhorizontal or stepped platform at low tide level**  
  **Dangerous access down steep or vertical cliffs; loose and falling blocks; cliffs often friable and undercut and subject to collapse; lower cliffs, slopes, and platforms subject to freak high waves, or ‘king’ waves; low-tidal platforms slippery with algae** |
<table>
<thead>
<tr>
<th>Rugged igneous rock high to low cliff (e.g., Leeuwin-Naturaliste Ridge)</th>
<th>Cliffs descending vertically or very steeply; strewn with blocks and boulders on lower slopes</th>
<th>Dangerous access down steep or vertical cliffs; slippery or rubble slopes; lower cliffs, slopes, and platforms subject to freak high waves, ‘king’ waves; low-tidal slopes slippery with algae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bouldery shores (e.g., Leeuwin-Naturaliste Ridge)</td>
<td>Moderately inclined shore underlain by boulders and blocks, with vertical to steep cliff in upper tidal and supratidal zones; low-tidal surfaces covered in algae</td>
<td>As above for bouldery shores; main risks are abundant unstable surfaces of boulder and block aggregate, slippery algae-covered surfaces, and ‘king’ waves</td>
</tr>
</tbody>
</table>

**Macrotidal coast (tide-dominated sedimentary coast)**

| Sandy (beach) shore (e.g., Cable Beach, Canning Coast) | Moderate to low gradient sandy shore with wave action; some beaches consistently subject to rip currents | Main risks are rapid tide inundation, shore currents, and unexpected formation rips that scour out the high-tidal and supratidal part of the beach |
| Sandy tidal flat (e.g., Eighty Mile Beach, Canning Coast) | Low-gradient sandy shore | Main risks are rapid tide inundation, occurrence of cone shells, and shark attack if in shallow water |
| Muddy tidal flat (e.g., King Sound) | Low-gradient mud shore with deep mud deposits | Main risks are rapid tide inundation, and sinking and being immobilised in the deep mud |
| Mangrove-vegetated muddy tidal flat (e.g., King Sound) | Low-gradient mangrove-vegetated mud shore with deep mud deposits | Main risks are rapid high tide inundation, and stalking by crocodiles |

**Microtidal wave-dominated sandy sedimentary coast; microtidal wave- and rip-dominated sandy sedimentary coast**

| Sandy (beach) shore | Moderate to Low-gradient sandy shore with wave action; some beaches subject to rips | Main risks shore currents, and unexpected rips that scour out the high-tidal to supratidal beach |
| Sandy tidal flat | Low-gradient sandy shore | Low risk |
| Muddy tidal flat | Low-gradient mud shore | Low risk |
| Mangrove-vegetated muddy tidal flat | Low-gradient mangrove-vegetated mud shore | Low risk |
| Estuarine shore (in that these shore types are coastal) | Sandy beaches, sandy tidal flats, muddy tidal flats, mangrove-vegetated tidal flats, and (locally) rocky shores | Generally low risk; the greatest risks are shark attacks if wading in shallow water, and sinking in sediment if accidentally traversing an area of methane upwelling |

Engineers who want to manage what they consider to be hazardous environments, and the public who seek to venture to the shore zone for recreation (e.g., swimming, fishing, viewing water sports, picnics), consider many of the sea cliffs and other rocky shore structures as dangers that need to be modified or managed. As a result, if geologically-important features are present on a rocky shore, a conflict of interest will arise where the scientific interests of geologists are weighed against the safety of people using the shore zone for recreation. Brampton (1998) and McNees (1998) addressed the issues of cliff conservation and protection, outlining methods and practices to help resolve conflicts. Ultimately, if the geological features are important enough and the rocky shore is dangerous to the general public then access would need to be restricted.
The issue of protecting fragile or vulnerable coastal geoheritage sites

Features of geoheritage significance along a wave-washed, sediment-abraded, and salt-weathered coast can include significant fossils, diagenetic features such as crystal rosettes, excellent exposure of (glacially) dropped pebbles, cobbles, boulders and their relationship to enclosing sedimentary rock, excellent exposure of dykes with chilled margins, exposures of pillow lavas and their contact with underlying sediment, well-exposed sedimentary structures, well-defined tectonic structures (such as folds), significant stratigraphic sequences, and exposure of unconformities, amongst many others. A range of such geological features and contacts are illustrated in atlases, guide-books, and texts on Geology and Geoconservation dealing with sedimentary, metamorphic, and igneous rocks, where classic exposures are in the coastal zone (Pettijohn & Potter 1964; Snead 1982; Sale et al. 1989; Kelletat 1995; Wimbledon & Smith-Meyer 2012). An important aspect of geoconservation is the protection of such sites of geoheritage significance. This will include: 1. avoiding degradation of the site by walking and trampling; 2. avoiding activities that lead to geomorphic degradation, e.g., inducing erosion through excessive walking through the site; 3. destroying or degrading excellent features by hammering, and 4. over-collecting of rock samples, and collecting atypical geological features, fossils, and minerals.

The extent that a site needs to be managed will depend on the significance of the site, how fragile or vulnerable the site is to trampling, walking, and collecting, how abundant the geological features of interest are at the site, and how frequently will the site be used. Clearly, to protect a site of geoheritage significance, a management programme specific to the site needs to be designed, bearing in mind the factors listed above.

The principles of coastal management in relation to conservation of coastal sites, its erosion, infrastructure, and safety are discussed by Brampton (1998), by Prosser et al. (2006, 2010), and in various papers in Hooke (1998).

Science and Education at a coastal geoheritage site

Sites of geoheritage significance function as scientific sites (research sites) and as education sites, or both. For the former, particularly if they are sites of scientific importance as research sites, they have to be managed so that they are not degraded and/or over-collected. The extent of management will depend on how significant is the site. For instance, the Iridium anomaly across the K/T boundary at Gubbio, Italy, the Archaean zircons as the oldest crystals on Earth in sandstones at Jack Hills, Western Australia, the Precambrian Ediacara fauna in sandstones in South Australia, and the Cambrian Burgess Shale fauna in Canada stand as four examples of sites of high-level global significance and can not, and should not, be subject to indiscriminate visits, sampling and over-collecting. However, to facilitate education and raising consciousness about Earth Heritage, such sites should be well sign-posted with explanatory information to describe to the public, amateur geologists, naturalists, and students the background to the sites and the significance of the sites and the significance of not collecting samples. Such sites, if made accessible to the public, geologists, scientists, and naturalists, should be managed with controlled access such as sign-posted board walks or pathways (Figures 12.4 &12.5)

On the other hand, other sites of less significance, though still functioning as research sites, need not have such stringent management control but still should be well sign-posted with explanatory information as discussed above. Hallett Cove in South Australia is an example of such a site (Giesecke 1999). It is protected from collecting, but it functions as an outdoor museum to educate the public and students.
Sites of geoheritage significance in general can function and should function as education sites because they provide outdoor “text books” on Geology in a natural setting. They just need to be well sign-posted with information boards at various levels of explanation to describe the content of the site, explain its significance regionally and, if applicable, its significance globally. Such sites can be regularly used for school excursions, for geotours, for university student excursions. Again, the level of significance of a site and the nature of the site will determine how much the geosite can tolerate the collecting of rocks, fossils, and minerals.

For geoparks, the area needs to be well designed as to geotrails and geosites to visit within the region. This will depend on the accessibility of sites within the geopark, and the descriptive information boards that relate the various geosites coherently to the regional setting. Saddiqi et al. (2015), for instance, present suggested geotrails in an aspiring geopark in Morocco. Though not coastal, the principles remain the same. Figure 12.7 illustrates the range of geosites that comprise important areas that could be used for geotours in the proposed geopark of the Walpole-Nornalup Inlet Estuary.

Signage and information boards for sites of geoheritage significance need to be designed ad hoc and specifically for the geosite and geopark in question. Theory and practice for signage, information boards, tourist literature such as brochures for sites of geoheritage significance, and the general conveying of geological information to the public are discussed by Page (1992a, 1992b, 1994) and Page et al. (1996) for the United Kingdom.
Chapter 13: Policy and Legislation in relationship to Geoheritage and Geoconservation
- Designing the Western Australian coastal geoheritage policy model

This Chapter deals with designing policy for coastal sites of geoheritage significance in Western Australia. As discussed in Chapters 9, 10 & 11, Policy can outline a philosophy of approach, or refer to guidelines on how to view and manage the environment, or provide management/conservation criteria and procedures, or provide a code of practice for geoconservation. The Coastal Policy developed in this Thesis is that of an integrated approach involving planning and management and will follow the philosophy of approach of the Burra Charter (ICOMOS 2013) and the Legal Principles of the Brundtland Report (1987).

The structure of this Chapter is as follows:

1. A stratified model for the development of a Policy for Coastal Geoheritage
2. Procedures for developing a Coastal Geoheritage Policy at Level 1
3. Procedures for developing a Coastal Geoheritage Policy at Level 2
4. Procedures for developing a Coastal Geoheritage Policy at Level 3
5. Procedures for developing a Coastal Geoheritage Policy at Level 4

Stratified development of Policy for Coastal Geoheritage, Levels 1-4
As foreshadowed in Chapter 9, the term ‘policy’ is defined at four levels (Figure 13.1):

firstly, at the highest level, Level 1, that as an umbrella concept, or philosophy of approach, or a position statement that there is need for direct recognition of geoheritage and geoconservation (and specifically, coastal geoheritage and geoconservation) within Western Australia in its framework of nature conservation within State Legislation and, Federally, in the EPBC Act; this includes definitions;

secondly, at the next level, Level 2, that the Geoheritage Tool-kit be applied to coastal Western Australia to systematically identify, evaluate, and prioritise sites of geoheritage significance at the scale of geosites and geoparks;

thirdly, at the next lower level, Level 3, that of generalised principles of actions and procedures to be followed for the range of geosites and geoparks; and,

fourthly, at the lowest level, Level 4, that of a more practical and detailed outline of methods to apply principles of geoheritage and geoconservation and geo-management that may differ at the site-specific level varying on geological region, type of information at a site, and type of location.

The principles and philosophy of these levels of Policy development and application are diagrammatically illustrated in Figure 13.1.
Procedures for developing a Coastal Geoheritage Policy at Level 1

In the first instance, a Policy, or philosophy of approach, should be adopted in Western Australia that Geology be afforded the same status as biodiversity. This would mean that the terms ‘geoheritage’, ‘geodiversity’, and ‘geoconservation’ would be appropriately inserted into current environmental and conservation laws and legislation to formally address the need to conserve geological features. This would be developed at the State level with a revision of the Environmental Protection Authority EPA Guidance Statement 33, parts B8 Landscape and Landforms, Chapter B9 Karst, subterranean wetlands and fauna, and Federally by the Department of the Environment. At this level, policy is referred to as “Geoheritage Policy” (Table 13.1) and, in fact, could relate to all matters of Geoheritage and Geoconservation, whether coastal or inland. This would be Level 1, as referred to earlier. The Legislation where this could be addressed in Western Australia is under the Environmental Protection Act 1986, in a revision of the processes the EPA may apply to land-use planning and development in Western Australia under EPA Guidance Statement 33. The overarching guidance applicable to planning and landscape issues has been prepared by the Western Australian Planning Commission (WAPC) and includes State Planning Policy (SPP) No. 2 Environment and Natural Resources Policy (Government of Western Australia 2003b). This SPP requires that planning strategies, schemes and decision-making should identify and safeguard landscapes with high geological, geomorphological or ecological values, as well as those of aesthetic, cultural or historical value. The Planning and Development Act 2005 allows for the classification or zoning of a scheme area for a range of purposes that include areas ‘for protection of the environment or landscape’ (Environmental Protection Authority of Western Australia 2008a, 2008b) and the EPBC Act (1999) at Federal level.

Table 13.1: Geoheritage Policy at the State and Federal levels

<table>
<thead>
<tr>
<th>The terms ‘geoheritage’, ‘geodiversity’, and ‘geoconservation’ be appropriately inserted into current environmental and conservation Laws and Legislation and accompanying Policy documents to formally address the need to conserve geological features, specifically in the Environment Act for the State of Western Australia and in the EPBC Act at Federal level.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any accompanying literature/documents should refer to relevant scientific papers and/or lay-person oriented brochures that define and deal with Geoheritage, Geodiversity, and Geoconservation.</td>
</tr>
<tr>
<td>In addition there should be recognition that Geology be afforded the same status as Biodiversity.</td>
</tr>
<tr>
<td>The introductory text from Geoheritage Policy of the Geological Society of Australia, outlining its Heritage conservation objectives, should be modified to reflect general geoheritage values (which will encompass coastal geoheritage), and Australia-wide and State application, and inserted into the Policy statement and into Legislation – this modified text is as follows:</td>
</tr>
<tr>
<td>1. promote the understanding and conservation of the geological heritage of Australia;</td>
</tr>
<tr>
<td>2. liaise with State Government agencies involved in conservation and Nature in the application of criteria to be used for the selection of geological features worthy of protection and preservation in the National and in the State interests;</td>
</tr>
<tr>
<td>3. identify, document and evaluate the significance of geological features through the various States;</td>
</tr>
<tr>
<td>4. maintain liaison with the relevant State Government agencies and NGOs on Geoheritage matters.</td>
</tr>
</tbody>
</table>
Procedures for developing a Coastal Geoheritage Policy at Level 2

In the second instance, given the vast and diverse geology and geomorphology of the coast of Western Australia and mainland Western Australia, as a policy directive, the Geoheritage Tool-kit should be systematically applied to identify, evaluate, and prioritise sites of geoheritage significance at the scale of geosites and geoparks along coastal Western Australia and, later, within mainland Western Australia. For coastal Western Australia, this would involve government agencies and NGOs applying the Geoheritage Tool-kit to extend investigations to encompass the entire coast of Western Australia. At this level, policy is referred to as “Policy for Application of the Geoheritage Tool-kit”. This would be Level 2 (Table 13.2) as referred to earlier.

**Table 13.2: Policy for Application of the Geoheritage Tool-kit at the State level**

<table>
<thead>
<tr>
<th>For coastal Western Australia, government agencies and NGOs in Western Australia should collaborate and systematically apply the Geoheritage Tool-kit to extend investigations of this Study to encompass the entire coast of Western Australia so that the sites of geoheritage significance at geosite scale and at geopark scale are identified.</th>
</tr>
</thead>
<tbody>
<tr>
<td>At a later date, but still at Level 2 Policy, the sites should be described as to their geological ‘essentials’, compiling an inventory of geological features (Step 2 of the Geoheritage Tool-kit), and evaluated as to their significance (Step 5 of the Geoheritage Tool-kit), and prioritised to determine what level of protection is required and to develop management plans (Step 6 of the Geoheritage Tool-kit).</td>
</tr>
<tr>
<td>The sites of geoheritage significance should be entered into a database with information on (a) location in terms of latitude and longitude, (b) brief description of the site, (c) classification of the site in terms of whether a reference site, cultural site, geohistorical site, or area of active modern processes, (d) for coastal sites, classification of the site as to one or more of the twelve coastal types, (e) list of geoheritage essentials and their scale, (f) key International or National features of the site, (g) level of significance of the site, and (h) classification as to category of conservation (cf., Figure 2.5).</td>
</tr>
</tbody>
</table>

In this Thesis, some 44 sites were examined in the field as described in Table 5.1. Of these, four sites were investigated and assessed in more detail at the regional (geopark) scale, viz., the Kimberley Coast, King Sound and its tide-dominated delta, Leschenault Peninsula and its leeward estuarine lagoon, and the Walpole-Nornalup Inlet estuary. Another four sites were investigated and assessed in more detail at the local (geosite) scale, viz., the Holocene limestone at Willie Creek, the Mesozoic Broome Sandstone at Entrance Point, the Pleistocene coral reef limestone at Point Leander, and the Pleistocene rocky shore and beach-to-dune sequence at Muderup Rocks. The remaining 36 sites examined in the field have not been subject to the same level of assessment as was directed towards the eight sites described in Chapter 8. The plethora of other possible sites of geoheritage significance along the rest of coastal Western Australian (beyond the 44 sites examined in this Thesis) remains unexplored.

Therefore, as policy, Western Australia, at Level 2, should be investigating the coast for sites of geoheritage significance using the Geoheritage Tool-kit (Figure 7.1). This would systematically identify sites of geoheritage significance along the Western Australian coast.
Procedures for developing a Coastal Geoheritage Policy at Level 3

In the third instance, the term *policy* is used in this Thesis to refer to the set of generalised guidelines and procedures to identify, assess, preserve, and manage sites of geoheritage significance. This would mean that the generalised methods to identify, assess, preserve, and manage sites of geoheritage significance would be appropriately inserted into current environmental and conservation Laws and Legislation in the State and Federally. At this level, with a focus on generalised principles and procedures for coastal sites, policy is referred to as “*Policy for Coastal Geoheritage*” (Table 13.3).

At present, Western Australian government agencies and authorities involved with Conservation, Nature, and Geology (the Department of Parks & Wildlife, the Environmental Protection Authority of Western Australia, and the Geological Survey of Western Australia) have no policy for the systematic identification, listing, evaluation, and management of sites of geoheritage significance and, in this context, clearly no policies to address Coastal Geoheritage. A Policy for Coastal Geoheritage at the State level (Level 3) would be a major advance for Geoheritage and Geoconservation in the State.

### Table 13.3: Policy for Coastal Geoheritage at the State level

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Determine the essential and most important geoheritage feature(s) of geosite/geopark and geomorphic processes therein, and identify what is required to protect them;</td>
</tr>
<tr>
<td>2.</td>
<td>Prepare rationale why site is significant internationally, nationally, State-wide, or locally;</td>
</tr>
<tr>
<td>3.</td>
<td>Map occurrence of essential geoheritage feature(s) of the geosite/geopark and the geomorphic units and hazards, and partition the site into management zones/categories that (a) address the important features, (b) avoid danger zones, and (c) show where best to place pathways and signage; these maps will show zones of exclusion, visitor zones, sample collection areas, danger zones, access pathways, locations of educational geotrails, billboard or signage locations for information on the Geology, the importance of the site, and the types of dangers and caution required;</td>
</tr>
<tr>
<td>4.</td>
<td>Determine oceanographic setting of geosite/geopark and identify the natural hazards for visitors;</td>
</tr>
<tr>
<td>5.</td>
<td>Determine geomorphic setting of geosite/geopark and identify the natural geomorphic processes as hazards for visitors;</td>
</tr>
<tr>
<td>6.</td>
<td>Determine the biogeographic setting of geosite/geopark and identify the natural biological hazards for visitors;</td>
</tr>
<tr>
<td>7.</td>
<td>Prepare management plans for protection of site, including design and implementation of monitoring programme to periodically assess status of the geosite/geopark; management plans should include control of potentially damaging human activities;</td>
</tr>
<tr>
<td>8.</td>
<td>Design information boards;</td>
</tr>
<tr>
<td>9.</td>
<td>Design brochures (to Tourist Bureau);</td>
</tr>
<tr>
<td>10.</td>
<td>Prepare education brochures and signage to illustrate the geology of a site, the safety issues of the site, and management issues of the site;</td>
</tr>
<tr>
<td>11.</td>
<td>Inform local schools, colleges, universities, and community groups as to the importance of the site and the educational functions of the site;</td>
</tr>
<tr>
<td>12.</td>
<td>Liaise with agencies and NGOs to upgrade information about the site, and maintain a database of sites, their significance, and site descriptions;</td>
</tr>
<tr>
<td>13.</td>
<td>Publicise the presence of the geosite or geopark through Government agency channels and NGOs to inform the geological community, educational institutes, and naturalist/geological NGOs as to the importance of the site for geological reference and research, and for education.</td>
</tr>
</tbody>
</table>
Case examples of Procedures for developing a Coastal Geoheritage Policy at Level 4

While a generalised policy can be developed for the various geosites and geoparks as outlined in Table 13.3, there would be need for the design of a site-specific guidance notes or policy for the various sites to account for the geology, the environmental setting, the reason for what the site will be used, and the type of visitors that will be expected. So, in the fourth instance, the term policy is used in this Thesis to refer to the set of detailed guidelines and procedures to identify, assess, preserve, and manage sites of geoheritage significance at the site-specific level. With a focus on site-specific principles and procedures, this policy is referred to as the “Policy for Coastal Geoheritage Geosites/Geoparks”.

The “Policy for Coastal Geoheritage Geosites/Geoparks” would need to be designed for specific regions and sites to reflect the variation in geology and variation in coastal setting. This would be Level 4, as referred to earlier. In this context, the Walpole-Nornalup Inlet Estuary (Table 13.4) and Entrance Point (Table 13.5) will be used as case studies of geoparks for the design of this level of policy. The outline of more detailed guidelines for the Walpole-Nornalup Inlet Estuary and Entrance Point is beyond the scope of this Thesis. Rather, the scope and style of policy required at Level 4 is provided in Tables 13.4 & 13.5 to illustrate the principles of what is required. In principle, this level of Policy will address, at site-specific level, the attributes of the site, the importance of the site, the fragility of the site, the dangers of the site and steps to be taken to avoid these dangers, and management of the site.

Table 13.4: Case Study 1. Coastal Geoheritage Geopark – Walpole-Nornalup Inlet

<table>
<thead>
<tr>
<th>General information:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walpole-Nornalup Inlet is a complex twin ria estuary with diverse Quaternary stratigraphy, estuarine landforms and shores, estuarine coastal wetlands including peat shore wetlands, exposure of limestone and yellow sand relationships, deltas, a flood tidal delta, a barrier dune system, complex dune forms on the barrier, cliff exposures of Tertiary sedimentary rock, and a ‘rock tombolo’ (Figures 8.25, 8.28, 8.30-8.32, 8.35, &amp; 8.36). The key features of this area are accessed by road, by walking, and by boat (Figure 13.2).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Significance of area:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walpole-Nornalup Inlet is the most important and most complex estuary in Western Australia. It holds information about Cainozoic history in the wettest part of Western Australia, and many of its geoheritage features are of National and State significance (Figure 8.38).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hazards:</th>
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</thead>
<tbody>
<tr>
<td>The hazards of Walpole-Nornalup Inlet are few. But although it is microtidal, it has strong ebb and flood currents associated with the entrance channel to the inlet, and the open Southern Ocean shores have strong wave action, longshore current, and occasional rips. The cliffs of the ‘rock tombolo’ are relatively stable, but there can be the infrequent rock face collapse, so it is advised not to climb the steep surfaces, or shelter under or alongside cliffs and not to remain under overhangs. In particular, do not collect samples from cliffs by hammering where there are overhangs.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pathways and geotrails:</th>
</tr>
</thead>
<tbody>
<tr>
<td>A map showing access pathways and geotrails and boat routes to best view features of geoheritage significance is shown at the site (Figure 13.2). Pathways and geotrails are punctuated with information boards to explain the geology and the features of geoheritage significance (Figures 12.7 &amp; 13.2).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>What to avoid sampling:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Since this a site of National and State significance, and also a Marine Park (essentially a National Park), sampling is only permitted with a license. If sampling is permitted, avoid collecting rocks directly from cliff faces that will leave scarring, i.e., particularly do not collect such sedimentary rock directly from the cliff faces.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Management objectives:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain natural processes, no dumping of rubbish, no use of all-terrain vehicles, coast defences, maintain access to exposures.</td>
</tr>
</tbody>
</table>
Table 13.5: Case Study 2. Coastal Geoheritage Geosite – Entrance Point

**General information:**
Entrance Point rocky shore is a cliff-and-platform system that exposes excellent outcrop of the Broome Sandstone. The Broome Sandstone is a Mesozoic formation of sandstone, interlayered with siltstone, and claystone, and is lithologically variable with the different rock types illustrating accumulation in a tropical tidal flat. Features that illustrate tidal flat conditions are shallow tidal channel-fill of interlayered sand, siltstone, and claystone, mega-rippled sandstone, rippled sandstone, ripple-drift structures, flaser bedding, wavey bedding, mud cracks, reworked cracked mud (mud chips), bubble sand, and faunal burrows (Figures 8.40-8.43). Information on the sedimentological history of the Broome Sandstone as exposed in the cliffs is provided in the information boards.

**Significance of area:**
These cliffs illustrate the sedimentary sequence developed in a siliciclastic sand-dominated tidal flat environment. This type of sequence is rare globally and, as such, the outcrop has global significance as a natural classroom for illustrating Mesozoic tidal flat sedimentation.

**Hazards:**
Entrance Point is macrotidal with spring tides of magnitude 10 m. Care has to be exercised so that visitors are not caught by rising tides and strong tidal currents. At high tide, Entrance Point is also wave-dominated, and care has to be exercised in this wave environment. At low tide, the rock platforms can be slippery. Caution must also be exercised because crocodiles are known to visit this area during high water. Information on crocodile safety is available from the Tourist Bureau or from the Department of Parks & Wildlife.

The cliffs are relatively stable, but there can be the infrequent rock face collapse, so it is advised not to climb the steep surfaces, and not to remain under any overhangs. In particular, do not collect samples from cliffs by hammering where there are overhangs. Information on the danger of cliffs and crocodiles is provided in the information boards.

**Pathways and geotrails:**
A map showing access pathways and geotrails to best view the geology is shown at the site (Figure 13.3). Pathways and geotrails are punctuated with information boards to explain the geology and the sedimentological interpretation (Figure 13.3).

**What to avoid sampling:**
Since this a globally significant site, avoid collecting *in situ* rocks that show rippled sandstone, ripple-drift structures, flaser bedding, wavey bedding, mud cracks, bubble sand, and faunal burrows. Particularly, do not collect such sedimentary structures directly from the cliff faces so as to leave scarring. The area of Entrance Point also is Yawuru country (an Indigenous people) and so collecting sampling would need Yawuru permission.

**Management objectives:**
Maintain natural processes, no dumping of rubbish, no use of all-terrain vehicles, coast defences, maintain access to exposures.
Chapter 14: Summary, Discussion, Conclusions, and Future Directions

The major achievements of this Thesis were: 1. recognition that coastal geoheritage is a major and new endeavour in the field of geoheritage and geoconservation; 2. development of a science-based geoconservation framework for coastal Western Australia, addressing key stages from coastal classification, compilation of inventories, assessment, and conservation through to the development of model policies; 3. development of tools and procedures to undertake compilation of inventories and assessment in coastal geoheritage; and 4. production of a first-level assessment of coastal geoheritage sites using eight case study areas, and 5. design of policies for sites of geoheritage significance in a four-tier approach.

Geoconservation begins with selecting sites of geoheritage significance. In this regard, there needs to be a clear understanding of what is the scope of geology and geoheritage so that the process of site selection captures the range of sites that can be evaluated as having geoheritage significance. Thus, the early part of this Thesis focused discussion on the scope and scale and categories of geology and geoheritage, and the potential types of geoconservation sites. This range of theoretical subject matter is not something that has been explored in the literature and, as a result, many aspects of geology to date have fallen outside the net of geoheritage and geoconservation (e.g., the hydrology of an area, and in particular the hydrology of coastal areas, or the processes of diagenesis in an area, or the occurrence of rip channels and their stratigraphic-sedimentological products along a wave-dominated coast).

Accordingly, the beginning of this Thesis defined the scope of geology, geoheritage and geoconservation, formalised the scales of reference, the levels of significance of geoheritage sites, and the categories of geoheritage sites, and formalised the various types of geosites versus geoparks and described their various possible scales of occurrence, content, and levels of significance.

The four categories of sites of geoheritage significance (as type examples, or reference sites, as culturally significant sites, as geohistorical sites, and as modern landscapes where active processes are operating) needed to be addressed because they are very different in their scope and management. Each has different importance to Geology and Geoheritage and thus each should be treated differently in geoconservation, education, and management. A given site of geoheritage significance may qualify to be allocated to more than one category. Assigning a site of geoheritage significance to one or more of these categories allows for robust and consistent comparisons and more rigorous evaluation.

The same principles apply to the matter of scale. A key feature of this Thesis has been the emphasis that a significant geological feature can be microscale (zircon crystal of Jack Hills) or megascale (the Grand Canyon). Frequently, sites of geoheritage significance are larger scale features and, to date generally, there has been little emphasis on smaller scale features. Fossils and minerals sites are an exception to this. The individual species of fossils that comprise the Precambrian Ediacaran fauna or the Cambrian Burgess Shale fauna are small-scale geological entities; measuring centimetres in size, and generally these have tended to be the smallest features identified to be of geoheritage significance. In this study, the scale of features of geoheritage significance has been taken to the size of small crystals and microbiota with the recognition that zircon crystals (< 1 mm in size), snowball garnets, chronologically and climatically significant pollen and charophyte oogonia, and Precambrian microfossils have geoheritage significance (Schopf et al. 2007; Brocx & Semeniuk 2007, 2010b, 2011a; Semeniuk et al. 2015).
Finally, regardless of the size of the geological phenomenon being considered, whether it is terrane-scale, outcrop or bed scale, or small crystal scale, the significance of the geological feature needs rigorous criteria for assessment as to whether it is International, National, State/regional, or local in importance. The approach of evaluation used here, as illustrated in Figure 2.3, has been semi-quantitative. In contrast, while many authors and government institutions/departments, particularly in Australia, have allocated or evaluated sites as International, National, Regional, or Local, most commonly there has not been a clear set of criteria for differentiating these levels.

That features of geoheritage significance can be megascale to microscale in size and that they can occur in isolation (and embedded in a geological framework of no special significance), or occur in combination with other significant geological features, and that geological features can be categorised as to reference sites, types locations, culturally-important sites, geohistorical sites, and areas where modern processes and landscapes are developing, has led to a new classification for features and sites of geoheritage significance as illustrated in Figure 2.5.

A major outcome of this Thesis is the recognition that geoheritage in the coastal zone is special. Some of the reasons for this are that the coast, as a narrow interface between land and sea, is the unique intersection of the environments of sea, land, groundwater, and atmosphere and many of the processes and products along this zone are the outcome of complex physical, hydrochemical, aerochemical, and biological interactions between these environments. As such, coasts can present many products of geoheritage significance, from varying expression of coastally-developed erosional landforms, to products uniquely sedimentologically, biogenically or diagenetically constructionally developed as a result of the interaction of coastal processes, to sea cliffs that reveal Earth history. Geologically, geomorphically, sedimentologically, and biologically the coastal zone can be comprised of eroding shores (such as rocky shores of outcropping bedrock, or relict sedimentary eroding shores), sedimentary accretionary environments (manifest as deltas, beaches and beach ridges, coastal dunes, tidal flats, amongst many others), and biogenic zones (resulting, for example, in coral, algal, oyster, and other reefal coasts).

The coast therefore can be studied in its complexity from a variety of emphases: that of coastal geomorphology (e.g., development of rocky shores, or beach cusps, or dune morphology, amongst others), sedimentology (e.g., the sediments and their dynamics on beaches, muddy tidal flats, coastal dunes, deltas, amongst others), biogenesis (e.g., development of coastal coral reefs, or other coastal bioherms and biostromes), and diagenesis (e.g., development of beach-rock coasts).

While there has been recognition that coastal outcrops present some of the best occurrences of rock sequences world-wide, and geoheritage practitioners in the United Kingdom have recognised this importance and have involved such outcrops in geoconservation and in coastal defense strategies (Hooke 1998), the full gamut of the potential of coastal geoheritage as a unifying discipline involving bedrock outcrops, coastal geomorphology at all scales, coastal sedimentology, diagenesis, rock-forming biogenesis, and proxies for sea-level history, palaeo-oceanography, and climate history, has not hitherto been recognised in the literature. In this context, and given that coasts can range from arctic to tropical climates, can traverse a wide range of oceanographic settings, can be eroding and rocky to accretionary and sedimentary, can be underlain by gravel, sand, or mud, or their combinations, and can reside in different biogeographic areas resulting in varied biogenesis, coasts perform a valuable geoheritage function that is different and more complex and more encompassing of a variety of natural geological phenomena than geoheritage features located on their immediately adjoining continental environments and submarine environments. This is the realm of coastal geoheritage.
Beyond its importance as a location for well-exposed outcrops, and location for unique and specific geomorphology, as well as a location for a wide variety of coastal sedimentation styles and products, the coastal zone, as a receiving interface for oceanic phenomena driven by climate changes and sea-level changes (Semeniuk 1995a), is also of geoheritage significance in that it records, and has recorded, the history of the Earth’s climate and oceanography in the Holocene. Such history is recorded via a variety of proxies.

The proxies for sea-level history, climate history, and palaeo-oceanography as geoheritage features are expressed in coastal geomorphology, coastal sedimentology, and coastal biology/palaeontology. In the literature, proxies for sea-level history, palaeo-oceanography, and climate history have been recognised and described generally around the globe (for example, Emiliani 1955; Shackleton 1967; Wefer et al. 1999; Henderson 2002; Lear et al. 2002; and Bauch & Polyakova 2000, 2003). Specifically along the Western Australian coast, the rich reservoir of information recorded as proxies for climate history and sea-level history are in the stratigraphic sequences and their lithological content, and in the palaeontology and micro-palaeontology. These proxies have been described and used by Semeniuk (1981), C A Semeniuk (2007) and Semeniuk et al. (2011) for climate history, Semeniuk & Johnson (1982, 1985), Semeniuk (1985a; 1996b, 1998, 2008), Playford (1988), Searle et al. (1988), Semeniuk & Searle (1986) and Semeniuk et al. (2011) for sea-level history, and Semeniuk (1996b) for sea-level history and palaeo-oceanography. Such archives of sea-level history, climate history, and palaeo-oceanography provide a valuable geoheritage resource and are encompassed now within a discipline of coastal geoheritage as sites of geohistorical importance.

Thus, as one of the most complex environments on the Earth’s surface, the coastal zone presents diverse and complicated products of erosion, sedimentation, biogenesis, and diagenesis, and well-exposed wave-washed, abraded (corrasion-eroded, from waves charged with sediment), and salt-weathered rock sequences. With its complexity and variability, the coastal zone lends itself to developing principles, classifications, and procedures for geoheritage, geoconservation, and a corresponding variety of policy to protect sites of geoheritage significance. This focus on geoheritage of the coastal zone in this Thesis, as noted above, is the realm of coastal geoheritage.

Coastal geoheritage begins with classifying and separating coastal types and, to this objective, in this study a new classification system for coasts was developed. Existing classifications of coasts such as those presented by Johnson (1919), Valentin (1952), Bloom (1965), King (1972), Shepard (1973), Davies (1980), Kelletat (1995), Woodroffe (2002) and Schwartz (2005) were too genetic, or did not integrate the gradations in the range of coasts from inundational to erosional to various stages of sediment-infilled as outlined in this Thesis, and did not address some specific coastal types (such as those formed by diagenesis) - accordingly, they were not useful for systematically separating coasts for description and comparative geoconservation. The new classification identifies twelve coastal types, categorising them as inundational, erosional, depositional, biogenic, diagenetic types, and their combinations, and geohistorical cliff types, and addresses all coastal types in Western Australia. The new classification, in fact, generally addresses all coastal types globally with the exception of coasts in glacial regions and coasts in active volcanic settings, two settings that are outside the scope of what exists along coastal Western Australia.

The Western Australian coast, along its 6000 km length and 22° of latitudinal range encompasses a diverse range of geological regions (viz., the Kimberley region, the Canning Coast, through to the Eucla Basin), several climate zones (from tropical to near-temperate, and humid to arid), encompasses large tracts that are rocky and erosional versus sedimentary and depositional with a large variety of coastal types, and fronts various oceanographic and coastal settings (from macrotidal to microtidal, from wave-dominated to tide-dominated to protected, to wind-dominated). In this context, with its variability of geological regions, and oceanographic and climate setting, and its wide variety of coastal
forms, Western Australia has provided an excellent starting point for developing and applying the coastal classification and for investigating coastal geoheritage and coastal variety with the objective to develop principles for coastal conservation and management and principles for coastal geoconservation policy. The classification of the Western Australian coast also provides a basis for comparing sites of geoheritage significance.

The next step after coastal classification is to develop and apply a selection-and-assessment method to identify sites of geoheritage significance. The method is termed the “Geoheritage Tool-kit” wherein, through a progressive series of six steps, sites are identified and assessed as to their geoheritage significance using their setting in geological regions, compiling an inventory of essential geoheritage features, determining their scale of geological features, assigning them to a geoheritage category, and determining their level of significance.

Techniques are available elsewhere in the World to compile an inventory of features of geoheritage significance (e.g., the methods used in the United Kingdom), but these methods are based somewhat on long-term knowledge and established geological regions and themes. They are not applicable to the Western Australian coast, firstly, because the geological regions and themes are different (e.g., Western Australia does not have a Jurassic Coast, nor a Chalk cliff coast), and the range of stratigraphic sequences and rock types along coastal Western Australia are markedly different to that of the United Kingdom. Further, coastal geoheritage in places such as the European shore along the Mediterranean, or the northern shore of Europe facing the North Sea, or the seaboard of the British Isles are located in latitudinally east-west oriented environments that have a relatively consistent climate, or alternatively, for the British Isles, do not transcend a major climatic cline. As such, Western Australia, traversing 6000 km of latitude, crosses from tropical to near-temperate; from humid to arid, fronts large stretches of three oceans and seas, which all have an effect on coastal forms and coastal geoheritage. Coasts of Europe and the British Isles thus do not provide models for Western Australia geologically, climatically and oceanographically and for methods of developing an inventory of features of geoheritage significance. Therefore, for Western Australia, in this Thesis, methods were developed to systematically identify, select, and evaluate sites of geoheritage significance from first principles.

In this study, from forty-four sites visited and described along the Western Australian coast that ranged from the extreme tropical north of the State to the extreme near-temperate south, the Geoheritage Tool-kit was applied to select four large-scale and four small-scale sites to identify and assess features of geoheritage significance. The four large-scale areas and four small-scale areas were selected so that they provided a diverse range of oceanographic and climate settings, a diversity of management issues, and a range of rock coasts and sedimentary coasts.

The large-scale areas, viz., the Kimberley Coast, the tide-dominated delta of the Fitzroy River in King Sound, the Leschenault Peninsula and its leeward estuarine lagoon, and the Walpole-Nornalup Inlet estuary, were described and assessed and considered to be able to function as the large-scale potential geoparks wherein there are inter-related geological features for geoconservation. The small-scale areas, viz., Willie Creek with outcrop of Holocene limestone, Entrance Point with outcrop of Mesozoic sandstone, Point Leander with outcrop of Pleistocene coral reef limestone, and Muderup Rocks Creek with outcrop of Pleistocene limestone rocky shores and a shoaling beach-to-dune sequence (now limestone), were described and assessed and considered to be able to function as the small-scale potential geosites wherein there are special features of scientific interest.
In this Thesis, for the forty-four sites studied along the Western Australian coast, and the eight areas where the Geoheritage Tool-kit was applied, the emphasis has been on geological aspects (such as stratigraphy, sedimentological features, and diagenesis, amongst other geological features) and less on geomorphological aspects. However, for the four large-scale areas used in the case studies (such as the Kimberley Coast, King Sound, and Leschenault Peninsula) there was also a degree of focus on coastal geomorphology and surface geomorphic processes. The same approach to defining and assessing areas geologically can be applied to those areas wholly comprised of features of geomorphological significance to create an inventory of sites from a geomorphological perspective. In this context, climate and oceanographic setting of the coast would become more relevant as these background factors play a large part in determining coastal geomorphology from macroscale to microscale.

Reviews of Policy and Legislation for Australia and selected other countries show that the matter of coastal geoheritage has not been directly addressed in policy and legislation by any one Nation globally, nor anywhere in Australia or Western Australia.

However, reviews were undertaken firstly to provide principles and definitions that underlie policies and legislation, and secondly to determine whether policies and legislation could be adapted for coastal geoheritage in Western Australia.

Some of the policies for geoheritage of the United Kingdom and the United States of America have relevance to coastal geoheritage in Western Australia in that criteria used for selection of sites, or rationale for the endeavour of geoconservation can be applied to refine selection of sites derived from applying the Geoheritage Tool-kit or used, at a National level, to justify the inclusion of the matter of geoheritage/geoconservation into legislation at the generic level of conservation (Level1 Policy of this Thesis).

For Australia, within a National legislative framework of conservation that is biocentric, and a Draft National Heritage Strategy that does not directly encompass geoheritage, there is little scope for general geoheritage and geoconservation, let alone coastal geoheritage. What advances had been made in the 1970s to 1990s towards geoheritage and geoconservation have been largely undone in the 2000s and 2010s. Thus, in spite of the promising advances made in the 1970s by the Australian Heritage Commission in establishing a Register of the National Trust and the Regional Forests Agreement (RFA) in identifying sites of geoheritage significance, and Commonwealth Heads of Government (COAG) Agreements to identify and protect sites of natural heritage, in comparison to the frameworks established to protect biodiversity in Australia, geoheritage has very little standing. However, some States within Australia have pursued geoheritage and geoconservation regardless of National policies or legislation in place. Further, as an NGO, the Geological Society of Australia, representing geologists throughout Australia, has a Nation-wide policy for geoheritage but nothing in detail that can be directly applied to coastal geoheritage in Western Australia.

In Western Australia, the review of policies and legislation was specifically focused on the Environmental Protection Authority, the Geological Survey, the Department of Parks and Wildlife, the Heritage Council and the National Trust to investigate what has been designed for the environment, wetlands, landscape and geoheritage. Instrumentalities, such as the Heritage Act of Western Australia (1990) and the Land Administration Act (1997) provide a means for the conservation of sites of geoheritage significance, and EPA Guidance Statement 33, Section B8 (Landscapes and Landforms), the State Planning Policy 2.6 State Coastal Planning, the Mining Act (1978), and the National Landcare Programme (jointly administered by the Department of Environment and the Department of Agriculture) provide a means by which sites of Geoheritage can be considered for management, however, these policies and legislation do not directly address geoheritage and geoconservation and, more importantly, do not specifically address coastal geoheritage.
The Geological Survey of Western Australia has adopted much of the Geological Society of Australia (WA Division)’s database on sites of geoheritage significance based on the work of Lemmon et al. (1979) and Carter (1987). Work was funded during the time that the Federal Government, (i.e., the Australian Heritage Commission), was actively engaged in identifying sites of geoheritage significance under the auspices of the National Trust (WA), and a limited number of sites, mainly restricted to the Pilbara Region, have been added to the Conservation Estate under the Land Administration Act 1997. However, given the size, geological complexity, and geological variety of Western Australia, this database, and those sites currently conserved under the Heritage Act of Western Australia (1990), the Land Administration Act (1997), and the EPBC Act (1999), very much under-represents the geoheritage of Western Australia. And again, the Geological Survey of Western Australia specifically does not address coastal geoheritage. This is because geoheritage, and specifically coastal geoheritage, is not included as a funded objective in the core “business” of these instrumentalities. For example, the Geological Survey of Western Australia’s core business is to facilitate the exploitation of natural resources through mining, the Department of Parks and Wildlife is focused on biodiversity and managing the biodiversity component of the Conservation Estate, and The Heritage Council and the National Trust are focused on Cultural heritage related to Indigenous culture, and buildings.

In an overview, policy for Geoheritage and Geoconservation in Western Australia and the coastal zone was developed in this Thesis incorporating themes, principles, and philosophy of geoconservation derived from the Burra Charter (ICOMOS 2013) and the Brundtland Report (1987) with some of the policy framework adapted from the United Kingdom, and from the United States of America. Specifically for Western Australia, however, there are four levels of policy developed in this Thesis presented in a stratified approach, ending with the design of very specific policy/policies, tailored to a given geological region, local geomorphology, and hazards due to oceanography, biogeography and geomorphology.

The major advances and contribution of this Thesis in the area of Geoheritage are the development of a science-based geoconservation framework for coastal Western Australia spanning critical stages from inventory, site assessment and conservation right through to the development of model policies; the development of a first level assessment of coastal geoheritage sites for Western Australia based on a new coastal classification; and the value and applications of the Tool-kit.

In detail, advances and contribution of this Thesis are:

- the development of concepts, principles, approaches and methods, and classifications with the objectives of identifying, selecting, and assessing coastal sites of geoheritage significance within Western Australia;

- in contrast to the rest of the World and the rest of Australia, Western Australia has its own geological story to tell; as such it offers remarkable, unique, and different geological and geomorphological features of global importance, for instance, the Kimberley ria coast, the Kimberley Precambrian sequences exposed at the coast, the tide-dominated delta in King Sound, and the Shark Bay stromatolites, amongst others, and can offer sites of special significance to the global network of geoconservation;

- for a site selected for its geoheritage significance, the main issues that need to be addressed are: 1. the level of protection needed to secure the site depending on its level of significance; 2. the types of protection required for the site given the nature of the materials that constitute the site; 3. the hydrodynamic or oceanographic setting of the site which will influence how the site responds to natural processes; and 4. the level of protection from the natural environment is required at the site, i.e., what potential dangers await students, geotourists, other visitors, and researchers;
Policy designed for Coastal Geoheritage sites is stratified involving four levels:

1. Level 1 Policy recognises that there is need for governance that includes direct recognition of geoheritage and geoconservation, specifically, coastal geoheritage and geoconservation, at the Federal level in the EPBC Act, and within Western Australia in its framework of nature conservation within State Legislation, *i.e.*, included under EPA Guidance Statement 33 under the *Environment Protection Act* (1986);

2. Level 2 Policy recognises that the Geoheritage Tool-kit can be applied to coastal Western Australia (and elsewhere) to systematically identify, evaluate, and prioritise sites of geoheritage significance at the scale of geosites and geoparks;

3. Level 3 Policy involves design of generalised principles of actions and procedures to be followed for the range of geosites and geoparks; and

4. Level 4 Policy involves a more practical and detailed outline of methods to apply principles of geoheritage and geoconservation and geo-management that may differ at the site-specific level, variation being dependent on geological region, type of information at a site, type of location, and type of coastal hazards.

**Future directions**

This study followed two strands: one that focused on the science of coastal geoheritage that involved classification of the Western Australian coast as a basis of identifying and evaluating sites of geoheritage significance using the Geoheritage Tool-kit, and the other that focused on policy development for the conservation of geoparks and geosites in the coastal zone.

Literature dealing with those coastal systems that have been already recognised globally as being of geoheritage significance was reviewed to provide a background to the development of a new coastal classification and criteria for geoconservation. The literature review also showed that the coast generally had not been previously considered fully as a category of geoheritage that warranted consideration in its own right. To assess sites of geoheritage significance, a Geoheritage Tool-kit was developed as a new research tool to methodically identify categories of geoheritage significance, identify sites, and assess their level of significance for conservation and management. This has opened up many avenues for future studies. Future directions for the cause of coastal geoconservation reside in both the arena of science-based identification and assessment of sites of geoheritage significance, and in the arena of policy development.

In the first instance, following on from this Thesis, vast tracts of the Western Australian coast can be further investigated using the Geoheritage Tool-kit to identify, evaluate, and classify as to level of management the potential sites of geoheritage significance. The 44 sites identified in this study would form a good starting point in that there is now a preliminary description of these sites, and from here they can be described and evaluated as geosites to the same level as Willie Creek, Entrance Point, Point Leander, and Muderup Rocks. Also, the areas of barriers of the Canning Coast, the limestone-barred embayments of the Canning Coast, the Dampier Archipelago system, the deltas of the Pilbara Coast, the limestone barriers of the Pilbara Coast, the cuspate forelands alternating with limestone rocky shores of the central Perth Basin, and the limestone cliffs of the edge of the Nullarbor Plain can be described and evaluated to the same level as the aspiring and potential geoparks of the Kimberley Coast, King Sound, Leschenault Peninsula, and Walpole-Nornalup Inlet Estuary.
There were a number of tracts along the coast of Western Australia that were not studied in any detail because of access problems or because they would have considerably extended the scope of this Thesis. These included the coast between Cape Range and Carnarvon incorporating the tectonically-uplifted Quobba Ridge, the coast of the Naturaliste-Leeuwin Ridge, the headland and barrier dune coast between Walpole and Albany, and the Plantagenet Coast. These can be explored in more detail to the same level as the tracts of coast of the Pilbara region and the Kimberley region. Also, specifically in this context, the full variety of sites of geoheritage significance of the World Heritage area of Shark Bay has not been fully explored. This area provides a rich reservoir of geomorphic coastal types, sedimentologic patterns, and rock types ranging in age from Cretaceous and Tertiary limestone, to Pleistocene marine, aeolian, and pedogenic limestone, Pleistocene red sand, to Holocene deposits. Shark Bay also provides a unique range of diagenetic and biogenic coasts. This region would be ideal to further apply the Geoheritage Tool-kit to identify, evaluate, and classify as to level of management the sites of geoheritage significance, and utilise them for education and geotourism.

Errami et al. (2013, 2015) demonstrated that the Geoheritage Tool-kit works well in inland areas in Morocco and, therefore, that the principles/techniques developed in this Thesis for Coastal Geoheritage can be applied to geology of inland Western Australia. Clearly, a major field of study is to apply the Geoheritage Tool-kit to inland Western Australia, and other parts of Australia, to identify and evaluate site of geoheritage significance, and to allocate them to categories of management.

In the arena of policy development, Australia is a signatory to international conventions such as the World Heritage Convention, the Convention on Biological Diversity, and the Ramsar Convention. This has led to National legislation, State agreements, government agency infrastructure, and a Tertiary education biased towards the conservation and management of the biotic environment. In contrast, awareness of the importance of geoheritage significance has major competition and conflict with notions that have their foundations rooted in resource development and, as such, has competing values with natural resource development. In an age where natural resources are recognised as being non-renewable, where the inter-generational importance/significance of Geoheritage is increasing, and where (geo)tourism is more and more viewed as an alternative to natural resource exploitation, there is scope to further investigate the legislative means by which the trend to deplete resources can be reversed, and instrumentalities that do not protect sites of geoheritage significance can be modified, extinguished or repealed. Concomitant with this would be a need to investigate how Geoheritage in its all its nuances of scope can be explicitly inserted into legislation, both Nationally and at State level.

In Western Australian, the Stratified Policy developed in this Thesis fits well within Guidance Statement 33 – Environmental Guidance for Planning and Development. As such, there is scope to investigate the inclusion of Geoheritage, which is now included in the IUCN Protected Area Governance and Management Manual (Crofts & Gordon 2015) into State Policy and Legislation. The Geoheritage Tool-kit used in the case study of the Kimberley Coast by Brocx & Semeniuk (2011b), one of the publications arising from this Thesis, is recommended by Crofts & Gordon (2015), in their contribution to the IUCN Protected Area Governance and Management publication, as a clear, logical and objectively-based methodological framework (essential for the identification of features and sites of geoheritage interest) for serious consideration by Nations and organisations embarking on the identification and development of protected areas for geoheritage.

Such utilisation of the Geoheritage Tool-kit, suggested at the international level, can form the framework within new legislative instruments for identifying and conserving sites of geoheritage significance.

This Thesis marks the beginning of Coastal Geoheritage as a geoconservation and policy/legislative endeavour and the potential use of the Geoheritage Tool-kit globally.
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Principles and Tools for Conserving Sites of Geoheritage Significance on the Western Australian Coast

FIGURES 1.1 – 13.3
Figure 1.1: Examples globally and in Western Australia of different geologic and geomorphic features at various scales and of various geoheritage significance. A: The Seven Sisters, Sussex, southern England; exposure of Cretaceous chalk stratigraphy, and coastal landforms developed by an erosional coast (coastal geologic and geomorphic features); B. Siccar Point unconformity (Hutton’s unconformity) between Silurian sedimentary rock and Devonian sandstone (geologic feature); C. Giant’s Causeway – hexagonal columns in basalt, Northern Ireland (coastal geologic and geomorphic features); D. The East Devon Coast in south-western England (coastal geologic and geomorphic features). E. Permian glacial erosional surface cut into Precambrian rocks, Hallett Cove, South Australia (geologic feature); F. Cliff coast at the edge of the Nullarbor Plain, southern coast of Australia (geologic and geomorphic feature). G. The Twelve Apostles cut from Tertiary limestone exposed along the coast of southern Victoria, Australia (geomorphologic feature); H. channel-form and bedded sandstone in an estuarine sequence exposed in the cliff cut into the Ordovician Tumblagooda Sandstone at Kalbarri National Park, Western Australia (geologic feature).
Figure 1.2: The range of climate and oceanographic settings, and diverse geology along the Western Australian coast.
A: Cape Range, western shore
B: Linear dunes, Great Sandy Desert
C: Hamelin Coquina, Hamelin Pool, Shark Bay
D: Buttes in the NW Pilbara
E: Limestone pinnacles at Cervantes
F: Fold in layered rocks exposed in wall of Hamersley Gorge, Karijini Gorges
G: Bunbury Basalt coastal outcrop at Bunbury
H: Sigmoidally folded metamorphic rocks, south coast Western Australia
Figure 2.1. Some examples in coastal and inland Western Australia of different geologic and geomorphic features at various scales and of various geoheritage significance, arranged in decreasing scale. A. Limestone range in the Cape Range region (geologic and geomorphic features); B. linear dune field in the Great Sandy Desert (geomorphic feature); C. Hamelin Coquina in Hamelin Pool, Shark Bay (coastal geomorphic and stratigraphic features); D. Buttes in the north-western Pilbara region (geologic feature, and geomorphic feature centred on an unconformity); E. The Pinnacles at Cervantes (geologic and geomorphic features); F. A fold in layered ironstone and chert developed above a local decollement, exposed in a gorge in the Hamersley Ranges, Karijini (geologic feature); G. Outcrop of the Bunbury Basalt at the coast, south Bunbury (geologic feature, and coastal geomorphic feature); H. Isoclinally folded metamorphic rocks, exposed in coastal cliffs in southern Western Australia (geologic feature, i.e., structural and metamorphic features).
Figure 2.2. The range of scale of geoheritage features, ranging from crystals, to outcrops, to cliff faces, and terranes.
Figure 2.3. Diagrammatic representation of the levels of significance applicable to geoheritage features. A: International; B: National; C: State-wide to regional; and D: Local. Note that for Pleistocene aeolianites in Western Australia, coastal north-western oolite-dominated types are separated from coastal south-western biogenic-dominated types. The regionally significant palaeosols occur within biogenic-dominated aeolianites in south-western and southern Australia.
Marine

Dominantly terrestrial with decreasing effect of marine influences to landward

- Anoxic pyritisation under freshwater conditions (decaying marine matter)
- Terrestrial soil development
- Terrestrial bioturbation
- Freshwater cementation and other diagenesis
- Solar evaporation
- Decreasing effect of evaporation driven by onshore winds
- Decreasing effect of dune remobilisation by onshore winds
- Coastal winds
  - Salt spray
  - Freshwater seepage
  - Diagenesis
  - Storms
- Marine biogenesis
- Marine bioturbation
- Marine anoxic pyritisation
- Marine cementation
  - Effect of tides
  - Wave action
  - Bubble sand development

Beachridge Plain

Active marine/coastal processes generally decreasing in intensity to landward

Gradational boundary

Terrestrial processes dominant, marine products now stranded
Figure 2.4. Conceptual diagram illustrating the change in type and intensity of a range of coastal processes and products in a gradient from the coast to inland across the marine/terrestrial boundary, and the decrease in effect of marine/coastal processes to landward. This diagram is intended to illustrate the gradational boundary where active marine processes largely cease and the inland stranded beach ridge plain is relict geohistorical category of geoheritage.

Figure 2.5. Conceptual diagram illustrating the range of sites of geoheritage significance, from geosites to the various types of geoparks.
Figure 2.6. Summary diagram showing the scope of geoheritage in terms of its conceptual categories, its scales of application, and potential levels of significance.
Figure 3.1: Diagram illustrating the decreasing scalar approach to describing natural history features in this study, using stratigraphy and sedimentology as an example, commencing at the largest scale with the geometry of a body and ending with the composition of grains that may comprise the body. At each scalar level, the terms applicable to that scale are presented and illustrated. Diagram from Semeniuk et al. (2011).
Figure 3.2: Global map showing locations of sites of geoheritage significance mentioned in the text.
Figure 3.3: Global map showing locations of sites of global geoheritage significance mentioned in the text that were accessed as part of the global literature review.
Figure 3.4: Map of Western Australia showing locations of all sites mentioned in the text. For more detailed map of the study sites in the Kimberley region see Figure 3.5.
Figure 3.5: Map of Western Australia showing locations of the 44 sites and areas that were studied as part of this Thesis.
Figure 3.6: More detailed map of the Kimberley region in Western Australia showing locations of the sites and areas that were visited and studied as part of this Thesis.
Figure 3.7: Map of Australia showing locations of sites of geoheritage significance mentioned in the text (Western Australian sites are excluded from this map).
Figure 4.1: Contrast between terrestrial and coastal geodiversity. A–D. Outcrops of the Tumblagooda Sandstone. A & B. Outcrop of the Tumblagooda Sandstone in Murchison River gorge, near Kalbarri. The walls of the gorge do not expose well the lithological and structural details of the Formation, in that joint-controlled vertical cliffs usually are iron oxide coated (1), and the general outcrop is weathered. Recent rock falls exposed weathered rock (2). C. Wave-washed, wind-eroded, and salt-weathered cliff face of the Tumblagooda Sandstone at Red Bluff, Kalbarri, showing well exposed lithological and structural features. A large channel-form is clearly evident in the cliff, and layering is prominent and traceable. D. Close-up of (C) showing lithological and structural details of trace fossils and layering (scale is 30 cm). E–H. Outcrops of Pleistocene calcarenites. E. Outcrop of calcarenite along a natural cliff several kilometres from the coast, showing crusted surface, and poor exposure of lithological and structural features. Some lamination is arrowed. The base of the cliff is covered in sand (as fans) and breccia. F. Coastal exposure of calcarenite in the Perth area, showing range of geomorphic features (platform, notch, visor, bench with micro-pinnacles or lapiés) developed as a result of shore
erosion and solution of Pleistocene calcarenite at North Beach, Western Australia. G. Rocky shore exposure of calcarenite at Mudurup Rocks (Cottesloe, Western Australia) showing well exposed stratigraphic, structural and lithological features brought out by wave erosion, salt weathering and wind erosion, viz., prominent lamination and cross-lamination. H. Rocky shore exposure of calcarenite at Mudurup Rocks showing well exposed laminated shell grit (arrowed interval), unconformably overlying (and underlying) a rocky shore overhang in older calcarenite; the overhang is a hard band, bored by echinoids (1), pholadids (2), and other lithophagic organisms (3); see Semeniuk & Johnson (1985). I & J. Contrasting upward-fining sedimentary sequences of a terrestrial system (a point bar) and a coastal system (a tidal flat). I. Point bar stratigraphy showing structures in sand, fining up to a mud sequence (modified after Walker 1979). J. Tidal flat stratigraphy showing structures in sand, in the interlayered mud and sand, and in mud (modified after Semeniuk 1981a). K & L. Contrasting the details of a mud sheet and a mud-and-sand sheet formed in a terrestrial system (a floodplain) with that of a mud sheet formed on a tidal flat. Note that the structures and lithology of the floodplain sediments are expressed over an interval of a metre or more, while the intricate details of structures in the mud of a tidal flat occur within an interval ~ 20 cm. The comparison contrasts the relative monotony of a floodplain sequence with the relative richness of features evident in tidal flat mud deposits. K. Details of structures of the mud sheet and a mud-and-sand sheet formed on a floodplain (information adapted from McKee 1966; McKee et al. 1967; Walker 1979 and Potter et al. 1980). L. Details of structures of a mud sheet formed on a tidal flat (information adapted from Reineck & Singh 1980 and Semeniuk 1981a, 2005).
Figure 4.2: Processes and products on a sandy beach (graded across the beach). Waves, tides, wind, fresh-water seepage, and biota interact with a sloping sandy shore producing a range of sedimentary products related to the slope gradient (information from Mii 1958; Panin 1967; Beall 1968; Boothroyd 1969; Clifton 1969; Clifton et al. 1971; Reineck & Singh 1971; Davidson-Arnott & Greenwood 1976; Semeniuk & Johnson 1982; Inden & Moore 1983; Allen 1984; Semeniuk 1997). The stratigraphy generated by lateral progradation and shoaling of the beach is also shown. The photographic inset shows the surface of a beach: selected geomorphic and sediment units of the beach are noted, with description of the types of sediments and structures that underlie them. The sand cliff marking the edge of the berm was cut within the previous 24 hours of the photography.
Figure 4.3: Processes and products on a rocky shore cut into Pleistocene calcarenite. Waves, tides, wind, fresh-water seepage, and biota interact with and have modified the calcarenite geomorphologically, chemically, mineralogically and biologically (information from Wentworth 1938; Edwards 1941; Emery 1945; Hills 1949; Fairbridge 1950; Guilcher 1953; Emery & Foster 1956; Emery & Kuhn 1956; Bird & Dent 1966; Semeniuk & Johnson 1985; Stephenson 2000). The small-scale stratigraphy and geomorphic features at various levels along the rocky shore, generated by erosion, sedimentation, and biota, are also shown. The photographic inset shows details of the notch, visor, and the craggy nature of the bench (with lapiés, pools, and fissures).
Figure 4.4: The five main end-member coast-forming processes in Western Australia with respect to scale. Marine inundation develops coastal forms mainly in the megascale to mesoscale range, and to a limited extent, at microscale. Erosion and sedimentation operate mainly at leptoscale to the mesoscale/macro scale, and to a limited extent, at megascale. Biogenic processes develop and influence coastal form mainly at mesoscale to leptoscale, while diagenesis develops and influences coastal form mainly at leptoscale and microscale.
Figure 4.5: Diagram using a fluvially-dissected landscape as a template showing coastal forms developed by inundation and other processes, with the initial development of coastal form by inundation, followed by its modification by erosion and sedimentation. The same processes can, in principle, be applied to other landscapes. The juxtaposition of the three drainage basins are not meant to imply that such a situation exists in Western Australia or elsewhere, but to illustrate the range of hinterland forms that may be inundated by the Holocene transgression.
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Figure 5.2: A. Simplified geological map of Australia. B. Annotated to show the effect of regional geology on coastal forms. West coast is contrasted with east coast.
Figure 5.3: A. Simplified topographic relief map of Australia. B: Topographic relief map showing the Great Dividing Range and its effect on coastal features along eastern Australia in contrast to the west Australian coast (modified after Brocx & Semeniuk 2014a).
Figure 5.4: Climate map of Australia showing the annual rainfall patterns. The eccentricity of the rainfall patterns results in a humid east coast and an arid central west coast.
Figure 5.5: Simplified topographic relief map of Australia showing the Great Dividing Range, and the sectors around the coast that define the climatic, oceanographic (wave and tidal regimes), and wind patterns (modified after Brocx & Semeniuk 2014a). The climatic, oceanographic and wind patterns of the west coast is different from the other coastal sectors.
Figure 6.1: Three-tier hierarchical approach of categorising a coast or coastal site for purposes of geoheritage assessment.
Figure 6.2: Coasts developed by marine inundation and other coastal processes on a fluvially-dissected landscape (sequence A) and on a terrain of Pleistocene limestone ridges (sequence B). Examples of these coastal types are shown in Figure 6.4. The central coastal types have been developed by simple marine inundation (A1 and B1). One trend shows results of increasing effects of erosion (A2–A3, and B2–B3), the other shows increasing effects of sedimentation (A4–A5 and B4–B5), with the final diagrams (A6 and B6) showing later erosion superimposed on coastal landscapes formed by sedimentation.
Figure 6.3: Coasts developed where erosion is dominant and has eliminated the pre-inundation morphology (gradation C1–C3), and where erosion has exhumed inselbergs (gradation D1–D3).
Figure 6.4. Coastal forms in Western Australia. A. Ria coast in the Kimberley Region (Coastal Type 1). B. Partly sediment-infilled ria coast in the Kimberley Region (Coastal Type 2). C. Partly sediment-infilled limestone barrier coast in the Pilbara Coast (Coastal Type 5). D. Limestone barrier coast in the Pilbara Coast with sediment infilling the inter-ridge swales (Coastal Type 5). E. Wholly erosional coast, the Baxter Cliffs along the edge of the Nullarbor Plains (Coastal Type 3). F. Coast formed by exhuming of inselbergs in the Esperance region (Coastal Type 4). Inselbergs on the coastal plain, still partly buried by Tertiary sediments, are visible in the background. G. Coast formed by exhuming of a valley-fill of Mesozoic basalt (the Bunbury Basalt) south of Bunbury (Coastal Type 4). H. Coast comprised of sedimentary deposits (shoaled tidal-flat sediments), with superimposed erosional features, viz., tidal creeks (Coastal Type 7).
Figure 6.5. Coastal forms in Western Australia. A. Coast formed wholly by sedimentation – a large delta, viz., the Ashburton River delta, Pilbara Coast (Coastal Type 6). B. Coast formed wholly by sedimentation – a barrier dune system, viz., the Leschenault Peninsula (Coastal Types 6 and 11). C. Coast formed wholly by sedimentation – a cuspate foreland, viz., Point Becher cuspate foreland (Coastal Types 6 and 11). D. Coastal form developed by modern processes, viz., ridge-and-runnel complex east of Esperance (Coastal Type 6). E. Coastal form developed by modern processes, viz., rips and their feeder channels in the Esperance area (Coastal Type 6). F. Coastal form developed by modern processes, viz., beach cusps in the Esperance area (Coastal Type 6). G. Cliff cut into Holocene limestone at Port Smith (Canning Coast) showing stratigraphic interface between the beach facies and dune facies located some 2 m above their modern position (Coastal Type 11). H. Cliff cut into the Broome Sandstone in the Entrance Point area (Broome) showing well-exposed stratigraphy, structures and lithology (Coastal Type 12); person for scale. I. Close-up of cliff shown in (H) showing details of sedimentary structures, cut-and-fill structure, sedimentary sequence, and well-exposed lithologies (Coastal Type 12). Tafoni are also evident in the lower part of the photograph.
Figure 6.6. Coastal forms developed by diagenesis and biogenesis in Western Australia. A. Tidal beach-rock ramp in northern Canning Coast (Coastal Type 9). B. Tidal beach-rock ramp in the Dampier area, Pilbara Coast (Coastal Type 9). C. High tidal cementation indurating the upper surface of shell beach in Shark Bay, with break-up of cemented crusts to form rock slabs (Coastal Type 9). D. High-tidal surface of truncated seaward-dipping sediment layers that have been cemented in bands, resulting in a coast in Shark Bay with exposure of alternating indurated and semi-indurated layers (Coastal Type 9). E. Patina of a thin aragonite crust on a beach-rock ramp at Broome (Coastal Type 9). F. Rosettes of gypsum blades, in an interlocking resistant meshwork, forming a sheet on and under the supratidal flat, Shark Bay (Coastal Type 9). G. Cemented pavement in the high-tidal zone in eastern L’Haridon Bight, Shark Bay (Coastal Type 9). H. Stromatolitic reef in middle ground and foreground, comprised of stromatolite heads and indurated sheets (Coastal Type 8); in background, cliff cut into Pleistocene Carbla Oolite (Coastal Type 12) at its type section at Goat Point.

Figure 6.7. The groupings of the 12 Coastal Types occurring in Western Australia. The suite of coastal landforms developed by marine inundation, increasing erosion and/or sedimentation, and biogenic activities and diagenesis, is grouped in the grey box, a group focused solely on modern coastal landforms. Geological features and sequences, Holocene sedimentary sequences, and earlier Holocene landforms that provide Holocene and pre-Holocene geohistorical information are placed into the second group.
Figure 6.8. A–C. Various sizes of spits in Shark Bay (east shore of L’Haridon Bight; northern Faure Island; and south of Eagle Buff). D–I. Various sizes and extent of rocky shores in Western Australia. D–H: The Baxter Cliffs, Eucla Basin. I: Port Warrander, Kimberley Coast. J: King Bay, Pilbara Coast. These examples illustrate coastal forms can have expression at various scales, from megascale to mesoscale.
Figure 6.9: The ancestral “gulfs” of Shark Bay, viz., the large peninsula of red sand and the large fretted peninsula of limestone. Coastal erosion has developed sandy shorelines, recurved spits, sand platforms, and (calcrete) breccia ribbons, as illustrated in the insets.
Figure 6.10: Giant concretions at Osmington, Bowling Balls Beach, and Moeraki Beach. A. Giant non-septarian concretions of Bowling Balls Beach in Miocene Galloway Formation in the Mendocino County, California, USA at Osmington; these concretions, cemented by calcite, overprint steeply-dipping flat-bedded and flat-laminated sandstone and shale (locally with contorted lamination) with the laminations and contorted laminae preserved in the concretions; layering in the concretion is evident in this photograph. B. The concretions of the Galloway Formation eroded and reworked into ‘bowling balls’ on Bowling Balls Beach. C. Giant non-septarian concretions embedded in Bencliff Grit of the Upper Jurassic Corallian Formation at Osmington; these concretions, also cemented by calcite, overprint shallow-water marine and inter-tidal cross-bedded grit and sandstone, with cross-bedding preserved in the concretions. D. Giant spherical concretion reworked from cliff at Moeraki Beach.
Figure 6.1: Tight isoclinal folding. A. Tight isoclinal folding in gneiss in the King Leopold Orogen (Yampi Sound); arrow shows the fold (width of field is 1 m). B. Isoclinal folding in ironstone and shale (greenschist facies) at Cossack, Pilbara Coast; core of fold manifests crumpling of layers (arrowed); (coin for scale). C. Tight isoclinal folding in metagabbroic and ganitic gneiss of the Leeuwin Complex of the Pinjarra Orogen in Leeuwin-Naturaliste region (granulite facies); (hammer for scale). D. Tight isoclinal folding in amphibolite gneiss of the Albany-Fraser Orogen, Albany coast, southern Western Australia (camera lens cap for scale).
Level 1: application of regional information to provide a setting and context for differing geology, climate, and oceanography along the coast to determine Level 2 categories and Level 3 detail.

In Western Australia, this results in eight regional geological coastal types, and various other coastal sectors based on geology, climate, and oceanography.

LEVEL 1:

Level 1 information determines style of Level 2.

LEVEL 2:

Level 2 provides framework for Level 3.

LEVEL 3:

Level 3: inventory of detailed features within a framework of Level 2, and the information is used in Level 1, using three different examples.
Figure 6.12. Application of Level 1 to Level 3 categorisation of Western Australian coasts. The three concentric lines of varying widths and styles circumferential to the coast represent, in generalised form, the extent of the tropical and subtropical coastline, the extent that a coastal sector is wave-dominated, tide-dominated, or wind-dominated, or mixed (the centrally-placed line) and, finally, the extent of macrotidal versus microtidal shores. Nomenclature and symbols for the cratons, orogens and basins in Western Australia are shown in Figure 5.1. Coastal types in Level 2 are drawn from Figures 4, 5, 9A, 9H, 10A and 10H. Coastal Type 10 at Level 2 derives from a limestone rocky shore at Port Hedland. Coastal Type 11 at Level 2 derives from the stratigraphic sequence preserved at Point Becher.
Figure 6.13. Contrast between Pleistocene calcarenites occurring along coastal south-western Australia and those occurring along coastal north-western Australia. The calcarenites along the south-western coast of Australia are biogenic calcarenites manifesting beach/dune sequences and, in a microtidal subtropical subhumid climate, have developed a platform, notch, cliff, and bench. The calcarenites along the north-western coast of Australia are oolitic calcarenites manifesting dune sequences and, in a macrotidal tropical arid climate, have developed a platform, notch, cliffs, and benches.
Figure 7.1: The Geoheritage Tool-kit.
Figure 8.1: The eight areas used as case studies in coastal Western Australia.
Figure 8.2: The ria form of the Kimberley Coast in Western Australia.

Figure 8.3. Rainfall, evaporation, tides, and cyclone tracks in the Kimberley region. (Climate data from Bureau of Meteorology 1973, 1975, 1988, 2010; tide data from Anon 2004). Map of average annual rainfall shows the extent of rainfall centred on the central north-western Kimberley Coast and its hinterland, and the decline in rainfall to north-east and south-west and the amount of rainfall that will recharge the drainage basins. Map of evaporation shows high evaporation across the northern coast, increasing southwards. Tide ranges are macrotidal in the area of King Sound to
Prince Regent River, and Cambridge Gulf, decreasing to mesotidal in the area of Drysdale River to Cape Londonderry. The tracks of cyclones show those that intersected the coast and those that passed offshore – the former having direct impact on the coast, the latter distally generating impacts by wind, waves, and high seas.

Figure 8.4. Geology of the Kimberley region (from Myers & Hocking 1988, with additions from Hassan 2004), and the sectors of the Kimberley Coast determined by geology.
Figure 8.5. Kimberley region rivers and drainage basins (from Department of Water 2006).
Figure 8.6. Annotated aerial photographs showing contrast between coastal forms developed on fractured sandstone, basalt, telepathic and haematitic sandstone, and folded rocks, with fracture-controlled ravines and embayments, and terracing controlled by the stratigraphy. Images from Google™Earth.
Figure 8.7. Major coastal forms of rias along the Kimberley Coast showing the variation in their size and shapes, annotated with the style of sedimentary deposits occurring within them. Bar scale for A, B, C, D, E, F & G is 5 km. The numbers refer to one of the eleven coastal forms mentioned in the text, and the letters A, B, C, etc. show the location of the example along the Coast.
Figure 8.8. Oblique aerial photographs showing geomorphic features of the Kimberley Coast. A. Typical coastal form in the Kimberley region – an island of eroding jointed sandstone with scree slopes, a tidal/subtidal zone of jointed rocks and veneer of gravel, and a high-tidal to supratidal zone of (bleached) wave-reworked gravel. B. Mt. Trafalgar, a laterite-capped mesa in the Prince Regent River area, showing the nature of landforms that occur at the coast (image courtesy of Yann Arthus-Bertrand). C. Marine inundated ridge and-basin topography (fold limbs) typical of the Buccaneer Archipelago. D. Spine of sandstone projecting as a peninsula into the sea. E. Crenulate shore formed by vertical sandstone strata. F. Crenulate shore formed by fractures and joints in sandstone. G. Sloping rocky shore formed by low angled inclined strata, with shoreline rubble boulders/cobbles. H. Bouldery shore formed by eroding jointed and bedded sandstone. I. Biogenic shore – algal biolithite fringing a sandstone shore and bouldery shore. J. Biogenic shore – algal biolithite fringing a basalt shore. K. Bar-and-lagoon system, with a sandy barrier. L. Bar-and-lagoon system, with a gravelly barrier. M. Mouth of the Berkley River delta with wave-generated sand ridges. N. Narrow ravine cut into sandstone, and a sandy barrier. O. Tempestite –blocks of sandstone perched on a structural platform of sandstone; cliff of sandstone in far-ground. P. Salt weathering forming a high-tidal pavement on dolerite.
Figure 8.9. Oblique aerial photographs showing cliffs of the Kimberley Coast. A. Simple sandstone cliff. B. Terraced sandstone rocky shore (terraces controlled by lithology). C. Sandstone overlying basalt with platforms and terrace developed on basalt (foreground) and cliffs in sandstone (far-ground). D. Sandstone overlying jointed basalt; platform developed on basalt, and cliff developed in sandstone; rounded pebbles derived from basalt and sandstone. E. Erosion of sandstone by mass wasting; collapse apron has formed a gravelly shore deposit which descends to the low tide zone. F. Inclined sandstone strata forming plunging shore; erosion by mass wasting forms a pocket beach of sand and gravel. G. Jointed sandstone forming scree being reworked along the shore into boulder slabs. H. Sandstone overlying basalt with cliff in sandstone, and scree slope on basalt; scree develops bouldery shore deposit.
Figure 8.10. Anthropogenic impacts annotated on ria coasts elsewhere globally, with rural, forestry, urban, industrial, and shoreline impacts, in comparison to the Kimberley Coast. A. Coast of Galicia, Spain (the coast has been outlined in white line). B. Port Jackson, Sydney. C. Kimberley Coast. Images from Google™Earth.
Figure 8.11. Application of the Geoheritage tool-kit to the Kimberley Coast. In inset A, the categories of geoheritage applicable to this area are highlighted in medium grey (the sites of cultural significance relate mainly to those of Traditional Owners). Only a selection of geoheritage features are illustrated in inset B. The full list of essential geoheritage features of the Kimberley Coast are assigned a level of significance in inset C (see text).
Figure 8.12. Precambrian rocks globally, their localised occurrence along the coast, and the climate setting of the ria coasts (Precambrian outcrops from Levin 2006; climate boundaries from Trewartha 1968). Few rias are cut into coastal exposures of Precambrian rocks. The examples of rias and fjords in Figure 8.13 are located as circled and boxed areas, respectively.
Figure 8.13. Comparison of the size, extent, and plan-geometry of some rias (upper part of diagram) and fjords (lower part of diagram) of the world in comparison to the Kimberley Coast.
Figure 8.14. Location map showing King Sound and the tide-dominated delta of the Fitzroy River.
Figure 8.15. Palaeogeography of the early Holocene King Sound depression and the progressive filling of the gulf with sediments. A. Pre-Holocene and early Holocene palaeogeography showing the course of the Fitzroy River, and subsidiary drainage basins (these subsidiary drainage basins become sub-embayments during the Holocene marine flooding of the area). B. With the Holocene transgression 7000 years ago, southern King Sound was preferentially filled with tidal flat mud (under mangrove cover) forming the Christine Point Clay. C. A major erosional episode followed, resulting in the scouring of the Christine Point Clay. D. On-going deltaic deposition filling the central King Sound depression and the erosional scours cut into the Christine Point Clay, with erosion becoming more dominant in the latest Holocene.
Figure 8.16. Tidal creek erosion leading to various sizes of creeks in King Sound (after Semeniuk 1980b). Images (A) to (F) show the gradation from creek initiation in mud cracks to large scale meandering creeks; ruler for scale in 'C' is 30 cm. The numbers refer to representative examples of the stages of tidal creek development by widening, deepening and lengthening as described by Semeniuk (1980b) with 1 = the smallest creek and 6 = the largest creek.
Figure 8.17. Stratigraphic cross-sections of the tidal flats in southern to central King Sound. A. Doctors Creek Formation of sand-to-mud shoaling stratigraphy. B. Doctors Creek Formation occurring in scours cut into the Christine Point Clay. C. Erosion of Mowanjum Sand to form spits/cheniers, and high-level (truncated) occurrence of Christine Point Clay.
Figure 8.18. Application of the Geoheritage tool-kit to the tide-dominated delta of King Sound. In inset A, the categories of geoheritage applicable to this area are highlighted in medium grey (the sites of cultural significance relate mainly to those of Traditional Owners). Only a selection of geoheritage features are illustrated in inset B. The full list of essential geoheritage features of the Kimberley Coast are assigned a level of significance in inset C (see text).
Figure 8.19: Aerial view of the Leschenault Peninsula and, to left, its leeward estuarine lagoon
Figure 8.20: Selected examples of key geological and geomorphological features of geoheritage significance in the Leschenault Peninsula area. A. Map showing geomorphic and vegetation units of the Peninsula and cross section showing the change from west to east from relatively high relief terrain to undulating plains (Semeniuk & Meagher 1981a). B. Map showing ridges and bands of submerged beach rock seaward of the Leschenault Peninsula (Semeniuk & Meagher 1981a). C. The complex stratigraphy of the barrier showing its internal units and their ages relative to MSL (Semeniuk 1985). D. Calcrete forming above the water table by tuart trees (Semeniuk & Meagher 1981b). E. Development of lenses of calcrete breccia floatstone in soils following decay and/or burning of storm-uprooted trees that have ripped up calcrete during their upheaval (Semeniuk 1986b).
Figure 8.21: Application of the Geoheritage tool-kit to the Leschenault Peninsula and its leeward estuarine lagoon. In inset A, the categories of geoheritage applicable to this area are highlighted in blue. In inset B, some selected features of geoheritage significance are illustrated, graded in decreasing scale from left to right. Under the column “regional to large scale”, the map of the barrier and lagoon shows a boxed inset 1, a transect labelled 2, and a boxed inset 3 – these are shown in detail as (1), (2), and (3) under the column of “large to medium scale”. Under “large to medium
scale”, there is (1) an oblique aerial view of the barrier showing mobile and vegetated
dunes, (2) a cross-section of barrier-to-lagoon stratigraphic relationships, and (3) the
map of submerged beach rock (whose legend is in Figure 8.20). Under “medium to
small scale” there is map of the landscape setting and associated vegetation, and their
cross-section, and a map of the asymmetric Collie River delta. Under “small to fine
scale” there is a photograph of the calcitised sea rush roots (from Semeniuk 2010), a
diagram of the relationship of calcrete to tuart trees and the water table, and a
photograph of a polished vertical slab of the calcrete (details of the calcrete profile are
in Figure 2). The bar scale for the calcitised sea rush roots and the calcrete in the
column of “small to fine scale” is 2 cm. In inset C. all features listed in Table 1 are
allocated to a level of significance to comparatively illustrate the range of features and
their significance.
Figure 8.22: The twin basin ria nature of the Walpole-Nornalup Inlet estuary (from Brocx & Semeniuk 2011 in Semeniuk et al. 2011).
Figure 8.23: Focus on the generalised geology of the southern coast of Western Australia (modified after Geological Survey of Western Australia 1989). A. The distribution of the various megascale geological units (e.g., the Yilgarn Craton, the Albany-Fraser Orogen, and its northern and southern subdivisions of Biranup Complex and Nornalup Complex, respectively, the Leeuwin Complex and the Perth Basin). B. Details of the Albany-Fraser Orogen showing the “knot” of the rocks of the Nornalup Complex dominating the southern to southwestern part of the Albany-Fraser Orogen, contrasting with local outcrops (outliers) of Precambrian rocks covered in Cainozoic materials in the southeastern part of the Albany-Fraser Orogen. The Walpole-Nornalup Inlet resides in the Nornalup Complex.
Figure 18.24: Stratigraphy of the Walpole-Nornalup Inlet area.
Figure 8.25: Tertiary stratigraphy of Coalmine Beach Peninsula.
Figure 8.26: Terrestrial and estuarine landforms of the Walpole-Normalup Inlet area.
Figure 8.27: Comparison of each of the four estuaries of the southern coast of Western Australia in terms of barrier morphology, wind directions to develop the parabolic dune orientations, and the shape of each estuary. The arrows show the direction of wind required to develop the orientations of the parabolic dunes on the respective barriers. The barriers of three of the estuaries (Broke Inlet, Irwin Inlet, and Wilson Inlet) show parabolic dunes largely oriented SW-NE consistently across the region. The Bellanger Barrier in front of Walpole–Nornalup Inlet has a component of SW-NE parabolic dune orientation, and a component of SENW parabolic dune orientation. The map of Irwin Inlet shows that the estuary was larger earlier in the Holocene and that, (through sedimentation and lagoon segmentation), it has evolved from an elongate, shore-parallel coastal lagoon into a twin “wetland” system – the eastern Irwin Inlet system, and the western Owingup Swamp system (the latter, a stranded estuarine basin).

Figure 8.28: The range of stratigraphic systems along the shores of the Walpole-Nornalup Inlet Estuary (from Semeniuk et al. 2011).
Figure 8.29: Contrasting stratigraphy along the estuarine shore with attenant contrasting hydrochemical effect (from Semeniuk et al. 2011).
Figure 8.30: The Deep River Delta and its components (from Semeniuk et al. 2011).

Figure 8.31: The Frankland River Delta and its components (from Semeniuk et al. 2011).
Figure 8.32: The Frankland River Delta and its components (from Semeniuk et al. 2011).
Figure 18.33: Classification of deltas into fluvial-dominated, wave-dominated and tide-dominated forms, the gradations between them, and examples of where globally well-known deltas lie on this ternary diagram (modified after Reineck & Singh 1986). The examples of the three deltas in Walpole–Normalup Inlet show asymmetry as a wave-dominated delta for the Walpole River, asymmetry, heterogeneity and some polygeneity for the wave-dominated Deep River Delta, and marked asymmetry, heterogeneity, and polygeneity for the Frankland River Delta. The approximate location of the three deltas, or components of the deltas, are shown on the ternary diagram, with the Frankland River Delta Delta showing the most marked partitioning of the delta in terms of its polygeneity.
Figure 8.34: Different intra-estuarine deltas in the Walpole-Nornalup Inlet Estuary are located in different energy regimes.
Figure 8.35: Annotated oblique aerial photographs of the tidal delta complex, showing the tidal channel, the flood-tidal delta, the ebb-tidal delta, and the current-parallel shoals along the channel. The flood-tidal delta is spilling into deep water of the basin of Normalup Inlet. The tidal-delta complex is set within the context of the Bellanger Barrier and a Precambrian rocky headland.
Figure 8.36: Stratigraphic profiles across four shoreline transects in the Walpole-Nornalup Inlet Estuary and radiocarbon dates and the ages of the samples. The cross-sections also show the position of present MSL and that of a previous MSL (from Semeniuk et al. 2011). The notation of the transects as WINC, BRJ, DRDE and TD-A refer to the transects presented in Semeniuk et al. (2011) and are located in the map of sampling sites of Walpole-Nornalup Inlet Estuary shown at upper right. The radiocarbon samples are from a 2920-year old peat in transect WINC located above the Holocene higher sea-level, from a 1600-year old peat in transect BRJ formed with sea-level at present position, from a 1540-year old humic soil formed in a swale of the barrier in transect DRDE with sea-level at present position, and from a 1250-1710 year old shelly sand formed in a tidal delta deposit with sea level 1.5 m above present position.
Figure 18.37: Focus on the more detailed geology of the southern coast of Western Australia (modified after Geological Survey of Western Australia 1989), showing the occurrence of the four estuaries along southern Western Australia in a context of geological setting (from west to east, these are (Broke Inlet, Walpole-Nornalup Inlet, Irwin Inlet and Wilson Inlet). Three of the estuaries (Broke Inlet, Irwin Inlet and Wilson Inlet) are shore-parallel as a result of a shore-parallel barrier on-lapping a plain of Precambrian rock, or on-lapping Precambrian rocks and Cainozoic deposits. Walpole-Normalup Inlet, though it has a barrier, is nearly wholly nestled in a terrain of Precambrian rock. The attributes of each of the estuaries are listed in summary form in this illustration.
Figure 38: Assessment of the geoheritage features of the Walpole-Nornalup Inlet Estuary, showing the categories of geoheritage sites in the area, a representative range of geological features at decreasing scale, and the assessment of significance of each of the geological essentials of the area. Most of the features rank as Regional to State-wide significance, while some are National significance, and one feature of International significance.
Figure 8.39: Willie Creek.  A. Map of the Willie Creek embayment showing the geomorphic and sedimentary units, and the occurrence of the Holocene limestone (from Semeniuk 2008).  B. Stratigraphy of the Holocene limestone showing sequence of the various lithologies and the superposition of the Willie Creek Calcarenite, the Kennedys Cottage Limestone, and the Horsewater Soak Calcarenite.  C. Close-up photograph of the laminated calcarenite of the middle beach facies of the Kennedys Cottage Limestone, and the conglomerate of reworked beach rock of the upper beach facies of the Kennedys Cottage Limestone.  D. Conglomerate of cobble-sized cyclone-reworked beach rock of the upper beach facies of the Kennedys Cottage Limestone.

Figure 8.40: Rocky cliff headland of Broome Sandstone at Entrance Point, Broome.  Part of this cliff is shown in more detail in Figure 8.41A.
Figure 41: A. Cliff face exhibiting a sequence of layered sandstone, overlain by a sequence of sediments formed in a channel-dominated environment with channels filling with interlayered sand and mud. B. Complex interlayered sandstone and mudstone layers developed in complex channel-forms. C. Single channel-form with undulating floor cut into sandstone, with channel-fill composed of interlayered sandstone and mudstone becoming more mudstone-rich upwards. D. Sand-filled channel that has been cut into a layered sand sequence. E. Layered/laminated sand that has been cut by numerous channels now filled with laminated sand. F. Cross-laminated sand (former megaripple) with mud occurring at the toe of the megaripple (base of the foreset lamination) and passing into the bottom set laminae.
Figure 8.42: A. Interlayered sheets of sandstone and mudstone, with the upper surface of the mudstone pocked with burrows. B. Ripples on a sandstone bed. C. Sandstone lenses and sheets interlayered with laminated mudstone sheets; sandstone shows ripple-drift lamination, and bidirectional cross-lamination (herring-bone structure) indicating deposition under tidal regimes. D. Sheet of sandstone showing ripple form in its upper surface and, in its interior, ripple-drift lamination and bidirectional cross-lamination (herring-bone structure) indicating deposition under tidal regimes. E. Flaser bedding in sandstone, *i.e.*, ripple-drift lamination with thin curved mud lenses in the ripple troughs typical of tidal flat sedimentation. F. Laminated sandstone with clasts of mud chips (derived from reworked desiccating/cracking mud sheets).
Figure 8.43: A. Upper surface of mudstone pocked with burrows. B. Bubble structures in sandstone bed with several vertical sand-filled burrows. C. Upper surface of mudstone showing desiccation cracks. D. Upper surface of mudstone showing desiccation cracks. E. Vertical section of mudstone sheets and sandstone, with the upper surface of the mudstone showing desiccation cracks. F. Laminated sandstone with bubble structures.
Figure 8.44: Overview of Point Leander Pleistocene coral reef with insets showing lithology within the coral reef and within the channel-fill.

Figure 8.45: A. Platy coral interlayered with sheets of biogenic calcarenite (shell fragment hash); the upper part of the coral plates are extending into upward-growing fingers of coral and ultimately into a crustose sheet of calcareous algae. B. Platy coral interlayered with sheets of biogenic calcarenite; the layer of platy coral plates passes up into staghorn coral; there are local thin sheets of calcareous algae. C. Fingers of staghorn coral crusted over and covered by coralline algae; the coralline algae also is acting as a cementing agent to the coral frame (cf. James & Ginsburg 1979). D. Reef framework composed wholly of staghorn coral.
Figure 8.46: The limestone cliff at Muderup Rocks and diagram showing the buried Pleistocene rocky shore, the lithologies in the beach/dune shoaling stratigraphy, and the yellow-sand-filled pipes.
Figure 8.47: Details of lithology in various parts of the limestone cliff at Muderup Rocks (for reference see Figure 8.46).
Figure 8.48: Origin through coastal erosion of the exhumed Pleistocene rocky shore platform that now forms a bench at Muderup Rocks (for reference see Figure 8.46).
Figure 12.1: Sea cliff at Kalbarri, Western Australia, showing excellent coastal exposure of stratigraphy, lithology, sedimentary structures, and ichnology but, if used for purposes of education and geotourism, safety issues of rock falls and terrain difficult and hazardous to access need to be addressed in information boards and with walkways.

Figure 12.2: An example of a land surface at Hallett Cove where safety issues and the possibility of human-induced geomorphic degradation (both deriving from indiscriminate walking) would need to be addressed. This land surface is highly susceptible to erosion and, as such, the Hallett Cove Conservation Park, in fact, has addressed this issue and has designated paths and boardwalks that allow visitors to observe the geology and landforms without increasing that erosion or compromising their safety.
Figure 12.3: The matter of sampling. Geo-management needs to address sampling where (through education activities and/or tourism) fossils, minerals, and lithologies are depleted from locations or where research-grade and iconic rock surfaces are degraded. In the example illustrated here at Hazelmere, southern England, the iconic cliff face of Mesozoic chalk has been drilled for samples.
Take a couple of hours to explore the Hallett Cove story. Follow the Glacier Hike and unravel the clues to ancient landscapes and climates, and get to know the local inhabitants.

To protect the fragile coastal soils, vegetation and geological features, please stay on the trail. Enjoy your visit.

Figure 12.4: Signage at Hallett Cove Conservation Park showing where geological features will be explained *en route*.
Figure 12.5: Style of tourism management at Hallett Cove Conservation Park, with board-walks, look-out, and information board, here overlooking the folded and steeply inclined Precambrian (Proterozoic) rocks, the unconformity between Precambrian rocks and the Permian sequence, the glaciated nature of the unconformity, and the modern shore platform cut into the Precambrian rocks (Giesecke 1999).
Figure 12.6: Diagram illustrating the progression from Geology, Geoheritage, Geoconservation, Geosites/Geoparks, Geo-management, Geo-education, and Geotourism.
Figure 12.7: Map of Walpole-Nornalup Inlet showing key sites of geoheritage significance.
Level 1 Policy
that as an umbrella concept there is need for recognition of geoheritage and geoconservation (and specifically, coastal geoheritage and geoconservation) within Western Australia in the framework of current State Legislation and, Federally, in the EPBC Act

Level 2 Policy
that the Geoheritage Tool-kit be applied to coastal Western Australia to systematically identify, evaluate, and prioritise sites of geoheritage significance at the scale of geosites and geoparks

Level 3 Policy
that of generalised principles of actions and procedures to be followed for the range of geosites and geoparks

Level 4 Policy
that of a more practical and detailed outline of methods to be designed at a given site, appropriate for the site, to apply principles of geoheritage and geoconservation and geo-management that may differ at the site-specific level dependent on geological region, type of information at a site, and type of location. Walpole-Nornalup Inlet as an example

Figure 13.1: Principles and philosophy of the four levels of Policy development and application. Details of
Figure 13.2: Map showing cliff faces, dunes, and other key sites of geoheritage significance within the network of suggested pathways, geotrails, boat-accessible routes, and sites for signage in the Walpole-Nornalup Inlet Estuary. The images shown here for the various sites would form the basis for annotated signage.
Figure 13.3: Map showing cliff faces, and other key sites of geoheritage significance within the network of suggested pathways and suggested signage in the Entrance Point area.