COASTAL COMPARTMENTS & SEDIMENT CELLS OF WESTERN AUSTRALIA: 1. REGIONS & PRIMARY COMPARTMENTS

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OBJECTIVES

The aim of this project is to define the principal coastal regions, coastal compartments and sediment cells discernable around the coast of Western Australia, from the Northern Territory border to South Australia according to the geologic and geomorphic structure of the coast. The objectives of the project are to:

1. Contribute to effective identification of marine and coastal landform units within the existing OZRA and Smartline geomorphologic classifications;
2. Add strength and rationale to existing processes for the selection of marine and coastal reserves;
3. Provide a base for the assessment of ecosystem services provided by coastal ecological processes; and
4. Identify unusual attributes and/or landform features which may have been missed in the current process for selection of marine reserves in the region.

Components of the project include:

1. Determination of broad coastal regions based on climate, geology and landforms
2. Identification of potential primary (regional scale) and secondary (sub-regional scale) sediment compartments based on known geologic features, landforms, ocean processes and sediment distribution.
3. Description of primary and secondary coastal compartments in terms of:
    (a) Apparent interaction between terrestrial and marine processes, with particular reference to identification of major areas of interaction between rivers, streams and estuarine coastal lagoons with the marine environment;
    (b) Any unusual attributes and/or landform features within each compartment or cell, with particular reference to areas currently being considered for selection of marine reserves; and.
    (c) Areas potentially susceptible to coastal erosion and /or accretion in response to changing environmental conditions.
4. Determination of the degree to which marine coastal & terrestrial reserves, as well as IMCRA V4 Sub-regions are incorporated in the potential primary and secondary sediment cells.
5. Compilation of a metadata listing of all information used in the analysis.

CONCEPTS & TERMINOLOGY

Identification of coastal sediment compartments and cells is a regionalisation process which divides the Earth surface into a hierarchy of geographical units for a designated purpose; see for example the review by Gentilli (1979:3-48) which examines physical regions in Western Australia. *Coastal regions* are large areas sharing similar environmental conditions, particularly with respect to variation in the occurrence of extreme synoptic weather events; tidal regime; geologic framework; dominant landscapes and/or seascapes; and aspect of the shore in relation to cardinal compass direction. Similarly, compartments and cells are increasingly smaller units within the regional hierarchy and therefore share some of the attributes defining the larger region. The focus of this project is on identification and description of the coastal compartments.

One objective of the project is to align description of coastal and marine environments with the scalar hierarchy employed by land use planners and currently adopted by the Western Australian Planning Commission (WAPC 2003). The regional hierarchy used herein is listed in Table 1 together with those of Gentilli (1979) and the WAPC (2003). Its limiting scales are linked to the detail of information required for the type of planning to be undertaken rather than the size of the units, and ranges from broad policy preparation to preparation of highly detailed local plans.

Herein, the nomenclature applied to regionalisation refers to coastal regions, compartments and sediment cells based on the dominant geology and morphology apparent at each scale, with a finer subdivision recognised within each of the three classes.

Coastal compartments are distinguished from sediment cells for the purposes of this report. Herein *coastal compartments* primarily relate to structural control by the regional geology on the plan form of the coastline. They are secondarily dependent on coastal aspect and large coastal landforms such as deltas and cuspate forelands visible at a scale of 1:250, 000. In contrast to the compartments, *sediment cells* are smaller three-dimensional units. They are functionally defined by the likely movement of unconsolidated sediments within geologic and geomorphic boundaries identifiable at scales of 1:50,000 or larger to a local level. In part the distinction is based also on the potential ease of determining a *sediment budget* from available information. Each of these concepts – compartments, cells and budgets - warrants description although all have been described elsewhere. For example see descriptions by Komar (1996), van Rijn (1998) and Short (1999).

COASTAL SEDIMENT COMPARTMENTS

Coastal sediment compartments are large, regional scale features of the coastline. They are comprised of a complex array of physical landforms and coastal processes in which the state of the environment is highly dynamic, varying over space and time. The array of landforms differs between adjacent compartments with respect to characteristic landforms, coastal processes or some combination thereof. For the purposes of this report, each compartment extends approximately from the landward reach of tidal waters to the offshore limit of State Waters, and thus includes the terrestrial coastal zone, intertidal shore, inshore and inner continental shelf waters (Figure 1).

A coastal sediment compartment is a natural management unit for the conservation of sediment and ecosystems as well as development of strategies for mitigation of environmental risks. Potentially, managing the coastline through an approach based on sediment compartments provides focus on management of change. It facilitates recognition of components within each compartment that are subject to different levels of susceptibility to change and provides scope for proactive adaptation to changing environmental conditions. This is one element of the rationale for suggesting marine conservation and management plans should be founded on coastal compartment concepts.

SEDIMENT CELLS

A sediment cell is a reach of coast, including the nearshore terrestrial and marine environments, within which movement of sediment is readily identifiable if not largely self-contained. As defined in the literature (Komar 1996), sediment cells are segments of the coast in which sediments that are being or have been derived from a common origin or source can be traced along transport paths to a sink where they are temporarily or permanently lost to the coast (Figure 2). For example calcareous sands originating as skeletal material from animals growing on an offshore reef near Mandurah in South Western Australia may be moved landward to comprise part of the beach at Secret Harbour and ultimately be blown into a dune in Warnbro Sound or moved into deep water off the continental shelf seaward of Rottnest. Exchange of sediment across boundaries between adjacent cells may occur, although it may be limited and highly variable. In this respect a sediment cell provides a natural unit for estimation of a coastal sediment budget (Dolan et al 1987; Komar 1996; Rosati 2005) as well as identification of areas undergoing erosion or accretion and the linkages between them. Boundaries can be fixed, due to the presence of rocky headlands or structures, or migratory in response to change the wave regime (Carter 1988). Although interruption at a cell boundary arguably should not significantly affect adjacent cells (Mc Innes *et al.* 1998) this may not always be the case, particularly in meso- and macro-tidal regions such as the Pilbara and Kimberley of North Western Australia. In such circumstances, tidal currents and discharge by tropical rivers during extreme flood events may move sediments around coastal barriers, even at a broad regional scale (Cooper & Pontee 2006).

Sediment Budgets

Bowen & Inman (1966) and Inman & Frautschy (1966) originally described sediment cells and devised a methodology for estimating sediment budgets. CERC (1984) and Dolan *et al.* (1987) reviewed the procedure. Sediment cells are currently used to identify marine management units in the United Kingdom (Hooke *et al.* 1996; Jewell *et al.* 1998; Mc Innes *et al.* 1998; Cooper *et al.* 2001; Hansom *et al.* 2004) and elsewhere (Rosati et al 1999; DHI 2000;Rosati 2005; Hart and Bryan 2008). They are not always used in the estimation of sediment budgets which also may be estimated as the movement of coastal sediments within an arbitrarily determined reach of coast. In either case sediment budgets estimate volumes of sediment, particularly sand in reaches of unconsolidated sedimentary coasts. Budget estimates include consideration of the volume of material derived from identifiable source areas, such as seagrass meadows or eroding headlands; transported along pathways, including the longshore component of nearshore water circulation; and lost to sinks, such as coastal dunes and offshore canyons.

Estimation of sediment budgets has been applied to coastal planning in places where engineered infrastructure is at risk from coastal erosion or harbour development is under consideration. For example, sediment budgets have been estimated for sections of coast including Busselton (Oceanica 2004), Port Beach (Barr 2004), Bunbury (PWD 1978), Dawesville (Byrne et al. 1987), Cape Preston (Damara 2008) and Port Hedland (GEMS 2008). Estimated volumes of material transported are commonly, but not always, based on numerical modelling of littoral and nearshore sediment movement. They seldom consider complete sediment cells or bioproduction of sediments from inshore habitats of significance for natural resource management and sustainability; such as bioproduction from seagrass meadows, reefs and benthic pavements that may be affected by the use of inshore waters.

Relevance to Marine Planning & Management

Recognition of coastal and marine compartments along the Western Australian coast has been established by Semeniuk (1986) and Bancroft (2003) through their recognition of the physical and biologic attributes at a hierarchy of scales as well as identification of the relevance of the hierarchy to planning and management. Just as catchment management incorporates sub-catchments; coastal management based on coastal compartment and sediment cell concepts also comprise a hierarchy of compartmental and cellular units and sub-units (Table 1). Each sub-unit is nested within higher units in the hierarchy and shares boundaries with adjacent compartments and/or cells. Interactions between and within cells conveniently could be accounted for in planning and management processes. Hence it would be ideal for management plan development to follow the hierarchy with strategic plans developed first, through to regional plans, local coastal plans, to finer site plans. The scaling would be approximately the same as is currently recognised at strategic, regional, local and site design levels for planning and management purposes.

Following the observations of Semeniuk (1986), the sediment cell approach has historically been applied in Western Australia for regional and sub-regional classification schemes describing the distribution of sediments and landforms (Searle & Semeniuk 1985; Sanderson & Eliot 1999; Stul 2005). It has also been used to a limited extent in coastal planning by Landvision (2000, 2001), Stul (2005), Stul *et al.* (2007) and Stul & Eliot (2006). These applications followed overseas initiatives in coastal management reported by Mc Innes *et al.* (1998), M[c] Glashan and Duck (2002) and Hansom *et al.* (2004). They sought to establish a practical planning approach specifically applicable to the Western Australian environment and its governance. Stul (2005, 2006, 2007) built on the physical concepts as part of a study of the Perth Metropolitan Coast completed in preparation of the Perth Coastal Planning Strategy (WAPC 2006). More recently, coastal compartments and sediment cells have been used in the USA as frameworks for habitat mapping and development of strategies for ecologically based fisheries management (AAAG 2008). The strength of the approach rests with its potential to provide a structure for integrated management of coastal and marine resources within the State Waters and close to the shore. Information suitable for underpinning the approach includes habitat mapping prepared by the WA Department of Environment and Conservation as a component of the selection process for zoning marine conservation reserves, see for example Bancroft (1999) and Bancroft and Sheridan (2000). Regional data has also been reported for North Western Australia Lynne et al (2007a) and Marine Futures (2009).

Application of the concept to marine resource management has relevance in terms of policy making, prioritisation of areas for closer examination, identification of areas of high bioproductivity and determination of areas at risk from environmental change. Determination of the extent to which comprehensive, adequate and representative (CAR) principles (TFMPA 1999) have been applied may be assessed according to the geographic extent particular forms of conservation have been implemented. Potentially this may provide information for consideration in the preparation of policy for the determination of marine conservation reserves and fish habitat protection areas. Compartments and cells also provide a structure for assessment of the comparative significance of different sections of coast for management purposes, such as assessment of natural resource values and/or provision of particular ecosystem services, including bioproductivity based on the basic levels of the marine food chain. Additionally, changing climatic and sea level conditions within coastal compartments and cells have a profound effect on inshore marine organisms through change in habitat linked to change in coastal processes and the sediment budget. The hierarchy of compartments and cells provides a framework from which to forecast and assess likely change for given scenarios of climate change and rise in sea level.

BACKGROUND

The Western Australian coast is one of the State's greatest assets in terms of its environmental, economic, social and cultural resources although it has always been threatened by the affects of changing weather conditions and coastal processes. At present several State Government agencies share responsibility for the management of marine resources. Two share responsibility for biological resources: the Department of Environment and Conservation through the Conservation and Land Management Act 1984, the Environmental Protection Act 1986 and the

Draft Environmental Protection (State Marine Waters) Policy 1998; and the Department of Fisheries through the Fish Resource Management Act 1994 and the Pearling Act 1990. Additionally, the Department of Planning and Infrastructure addresses land use planning and development issues specifically as they relate to the protection, conservation and management of the coast through the State Planning and Development Act (2007) and the State Planning Policy 2.6 (Western Australian Planning Commission SPP 2.6) In particular SPP 2.6 provides guidance on determining setbacks, including development setbacks, for protection against coastal processes such as erosion, sea level rise and severe storm events.

Potential pressures on coastal assets due to the natural variability of coastal processes are recognised in State Government policy and guidelines for the conservation and use of coastal resources. However, recently projected changes in climate and sea level (CSIRO 2007; IPCC 2007; Rahmstorf et al 2007) are anticipated to substantially impact on the natural resources of the coast, particularly those of the State and Coastal Waters and in close proximity to the shore. The projected changes may fall outside the scope of current policies since their extent is beyond the natural variability of climate and sea level over the historical period. This raises questions concerning both policy and the adequacy of current procedures for the identification and management of our natural resources. In some instances it raises questions of substance that have yet to be determined; for example the extent to which current marine parks and reserves are adequate for sustain marine resources in the foreseeable future.

In 1994 Chevis (1994) described development of the marine reserve system for Western Australia outlined by Wilson et al (1994) in terms of the application of a Delphic technique involving deliberation and collective decision-making by an expert scientific group with then current marine research experience in and knowledge of regions in the State Waters. Chevis (1994: 117) concluded the recommendations of Wilson et al (1994) provided a working document '*allowing for refinements as further data becomes available*". The document and its recommendations of were opened for public comment as was reported by CALM (1997) in accord with State Government policy for conservation of the environment and ecologically sustainable development. To date and under the CALM Act (1984) the refinement process has been incorporated in the planning process for establishment of particular marine conservation reserves. The process includes detailed scientific investigations of coastal and marine sites under consideration as well as public consultations that are completed as part of the selection process to determine zones of marine use for conservation and other purposes within each reserve. Whether the geographic attributes of the marine reserve system have been refined over time is a moot point.

Much of our detailed knowledge about nearshore habitats and marine ecology is fragmentary at best and focussed only on small areas considered to be of high conservation value. As a result it is highly unlikely the current marine conservation strategy based on Wilson (1994) encompasses the full range of biodiversity and bioproductivity in State Waters. This brings into question whether the strategy provides adequate protection of its natural resources for commercial and recreational purposes. Despite technologic and scientific progress in marine science since the public consultations of 1997 there does not appear to have been a systematic or public review of the specific recommendations of Wilson et al (1994) in the context of the adequacy or otherwise of the overall strategy. Further, there is apparent scope and urgent demand for such a review, particularly at a whole-of-government level and in terms of increasing public and commercial competition for use of marine resources. Throughout the workshops leading to and since publication of the report of Wilson et al (1994) the selection of areas for conservation in Western Australian Waters has been based on use of marine geomorphology as a proxy to identify critical life habitat for marine species. This approach has been given validity by a growing body of data suggesting the underlying geology and geomorphology of marine environments dictates coastal responses to sea level rise (Riggs et al 1995, 1996; Valvo et al 2006), as well as the location of critical life habitat for a variety marine species and may be used to advance the application of ecosystem-based management (Association of American Geographers 2008).

PROCEDURE

1. Primary Compartments

Several steps were used to identify coastal compartments.

First, boundaries of the compartments were identified according to table 2, below:

Table 2 Features used to establish the boundaries of each of the primary coastal compartments

Priority	Feature	Examples
1	Changes in bedrock geology	Metamorphic to sedimentary rocks; lithified to unconsolidated sediments
2	Rock structures (topography)	Rocky capes, peninsulas, termination of extensive cliffs
3	Geomorphic features (morphology)	Large cuspate forelands and tombolos; extensive sandy beaches
4	Change in aspect of the shore	Bald Head at the entrance to King George Sound; changes in aspect along Eighty Mile Beach

Major changes in lithology along the coast were identified from the 1:500 000 Geological Map. These provided the first approximation of boundaries for identification of the primary compartments around the coast of Western Australia from the border of the Northern territory to that with South Australia.

Second, the compartment boundaries were then adjusted with reference to the 1:250 000 Geological Map, the 1:100 000 Topographical Map Series and satellite imagery available on Google Earth 2008 ®. The adjustment was made to accommodate apparent change in the orientation of the coast as well as to incorporate complete landforms of regional significance. The selection of landforms was broadly in accord with the scheme proposed by Semeniuk (1986.) For example the delta of the De Grey River is a landform of regional significance.

2. Secondary Compartments & Sediment Cells

Third, once boundaries for the primary compartments were determined each was further subdivided to identify large-scale landforms of sub-regional significance. These secondary compartments have been based predominantly on landforms such as extensive tracts of coast with continuous beach or common dune formations. The terminology is loosely consistent with the second order landforms listed by Semeniuk (1986). The landforms were identified with reference to the 1:100 000 Topographical Map Series and satellite imagery available on Google Earth 2008 ®.

Fourth, the secondary compartments were then subdivided into a suite of sediment cells based on the coastal landforms present. For example, with down-drift distance along the cell shores on the South Coast cliffed dunes gives way to wider beaches with developed foredunes, and ultimately to broad beaches fronting active parabolic dunes and large mobile sand sheets. Such patterns have been used to identify compartments and cells at a hierarchy of scales. At all scales the geologic framework comprising the headlands and promontories structures the coast and was considered in the classification.

A full listing of the features used to define the boundaries is presented in Table 2.

METADATA

The following data sets were used:

AUSLIG, 1993. *Topographic Series, 1:100 000 Map Sheets for Western Australia.* Commonwealth Government, Canberra.

Geological Survey of Western Australia (GSWA), 2007. *Atlas of 1:250 000 Geological Series Map Images, Western Australia, April 2007 update*. GSWA, Perth.

Google Earth 2008. Images for the Pilbara Region. (http://www.googleearth.com)

Sharples, C., 2007. *Smartline* maps, compiled for the *Inventory of Potentially Unstable Coastal Landform Types for the National Shoreline Geomorphic and Stability Mapping Project.* University of Tasmania, Hobart.

COASTAL REGIONS AND PRIMARY COMPARTMENTS

REGIONS

Western Australia includes 12 regions subject to differences in the occurrence of extreme weather events; tidal regime; geologic framework; dominant landscapes and/or seascapes; and the aspect of the shore. These vary considerably in size from small regions such as the Northampton Region in the lee of the Abrolhos Islands (60 km) to the Kimberley (approximately 19 000 km). Their locations are identified in Table 3 and illustrated in Figure 4.

Comparison of the regions identified in this project with those of other classifications of the coast, for example those described by Gentilli (1979) and Short, (2006, 2005), revealed differences. These are apparently related to the geologic framework used to identify the regions shown in Figure 4, and long-term, geologic evolution of the coast. For example the Naturaliste Region extending approximately 94 km from Cape Naturaliste to Cape Leeuwin, is an Achaean horst block which adjoining the extensive east-west, Leeuwin- Naturaliste Ridge off the continental shelf. Its capes, bays and calcarenite limestone overlying granite and gneissic rocks differs significantly from the barrier dunes and sandy beaches set in the graben sunklands of Flinders Bay and Geographe Bay. Similarly, the broad salient comprising the coast of the Northampton Region between the Murchison River and broken Anchor Bay is a complex feature controlled by elongate limestone reefs that are sub-parallel to the shore and support a ridge of parabolic dunes. The salient is protrudes approximately 4 km from general trend of the coast between the Murchison River and Glenfield Beach. The reefs and dunes enclose the Hutt Lagoon in the southern part of the region and a broad foredune plain to the north.

PRIMARY COMPARTMENTS

Thirty seven primary compartments were identified from the twelve coastal regions of Western Australia. Their locations are identified in Table 4 and illustrated in Figure 5. Each compartment identifies a particular suite of characteristics based on geology, landforms and aspect. The variation is exemplified with reference to geological classification used in the Smartline database (Sharples 2007) and descriptions of morphology from the Oil Spills Response Atlas (OSRA) collated by the Australian Maritime Safety Authority (AMSA). The OSRA data base provides an estimate of the proportion of coast occupied by each landform type (Table 4).

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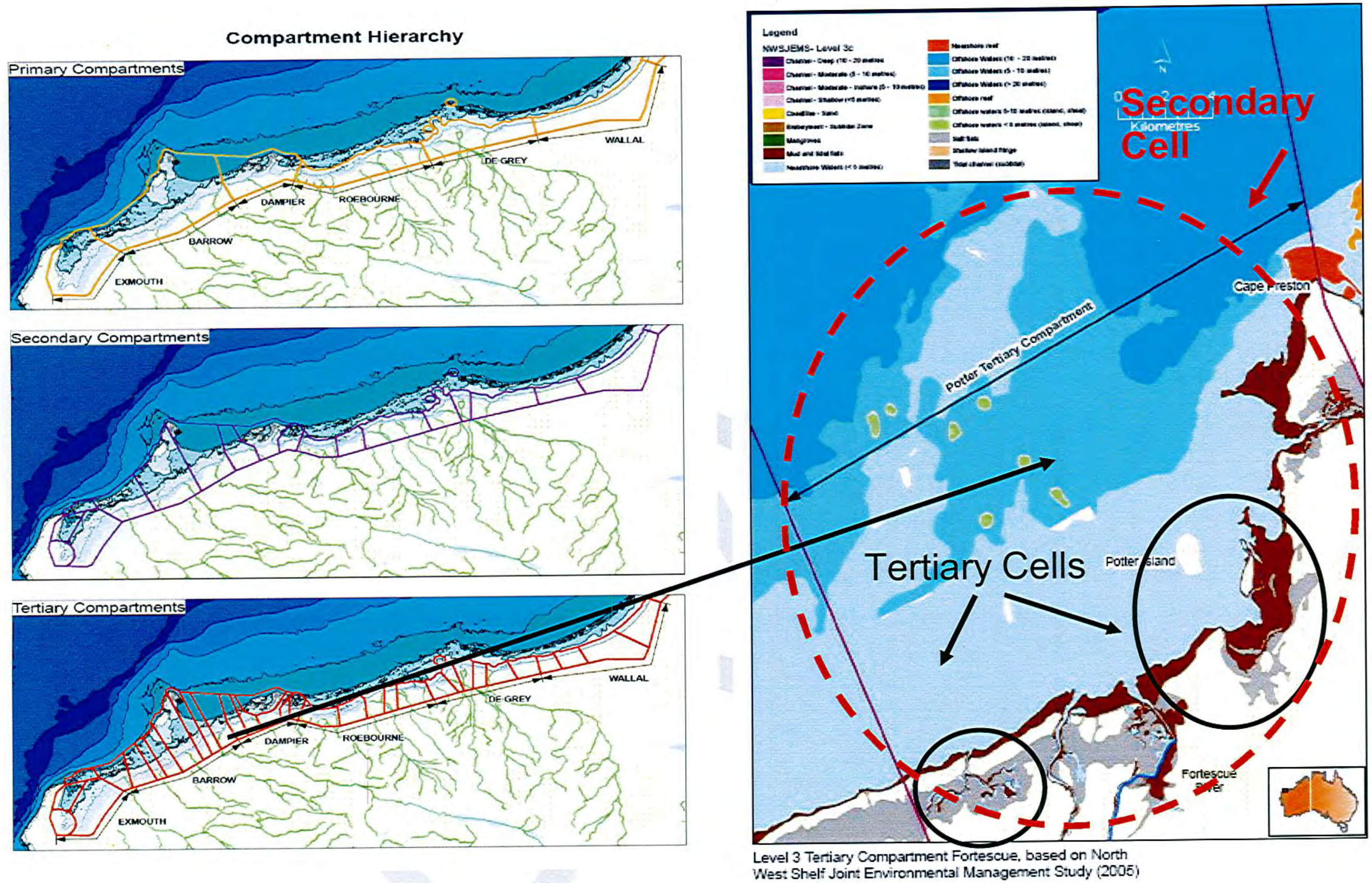
Table 1 **Scale and Size of Regional Units**

Scales after Gentilli (1979), the Western Australian Planning Commission (2003) and used in this report

Regions (After Gentilli 1979)			WAPC (2003)			Current Project		
Limiting scale preferred	**Indicative length of coast (Kms)**	**Example**	**Limiting scale preferred**	**Indicative length of coast (Kms)**	**Application**	**Limiting scale preferred**	**Indicative length of coast (Kms)**	**Application**
1:10 000 000	> 100 km	Kimberley Block	N/A	N/A	N/A	N/A	N/A	N/A
1:1 000 000	50 to 500 km	Perth Coastal Plain	N/A	N/A	N/A	1:1 000 000	50 to 500 km	Regional policy & guidelines related to coastal landforms
1:200 000	10 to 100 km	Eighty Mile Beach	1:100 000	100 to 1 000 km	Regional plans and strategies	1:250 000	10 to 100 km	Assessment of change to coastal processes & landforms
1:50 000	5 to 20 km	Cockburn Sound	1:25 000	1 to 100 km	Local plans and strategies	1:50 000	5 to 20 km	Sediment budgets and hazard assessment
1:10 000	< 10 km	Middleton Beach	1:1 000	100 m to 1 km	Site plans	1:10 000	< 10 km	Assessment of local sediment budgets



Level 3 Tertiary Compartment Fortescue, based on North West Shelf Joint Environmental Management Study (2005)

Figure 1 Coastal compartments and sediment cells

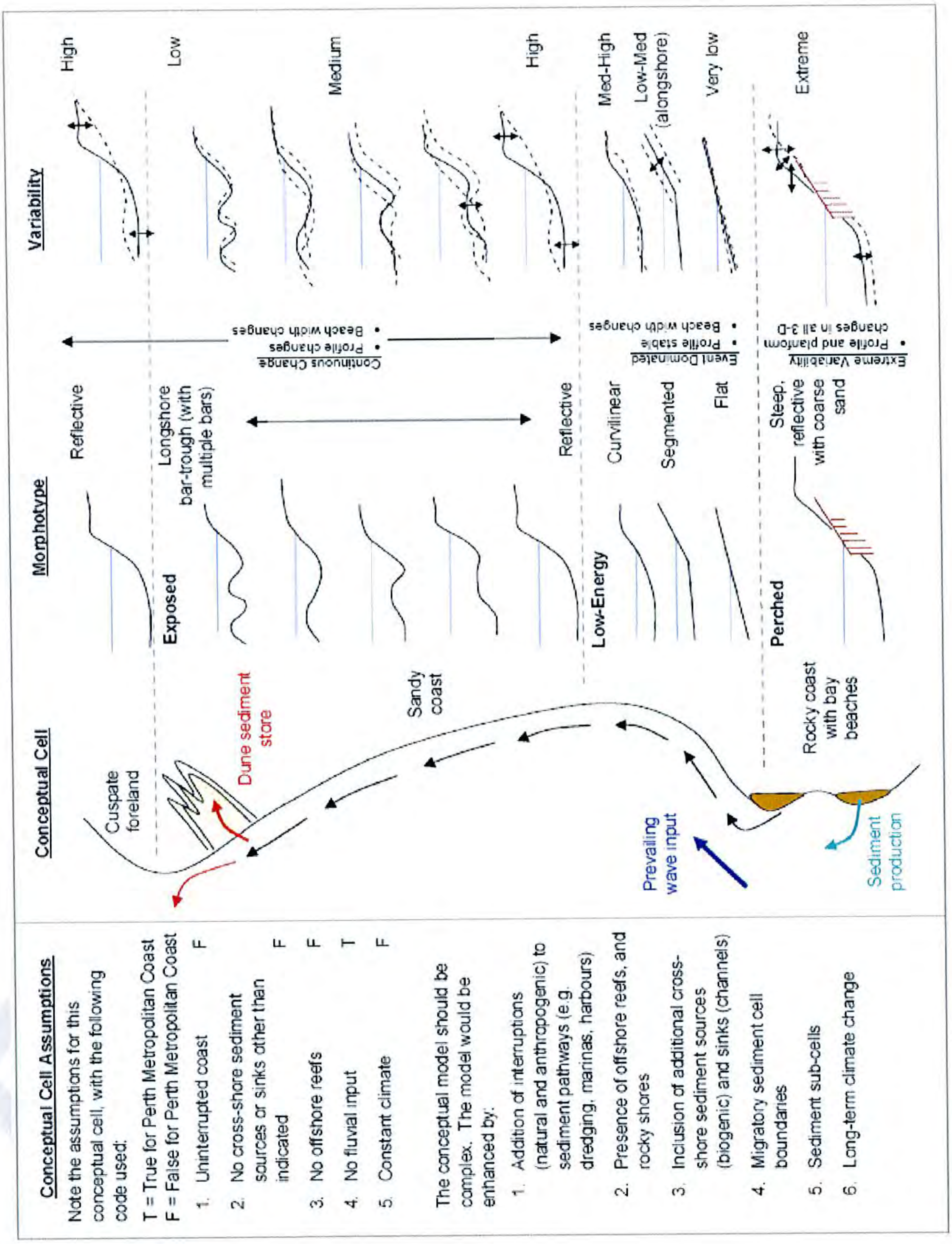


Figure 2 Beach morphotypes and variability associated with a sediment cell (From Stul 2005)

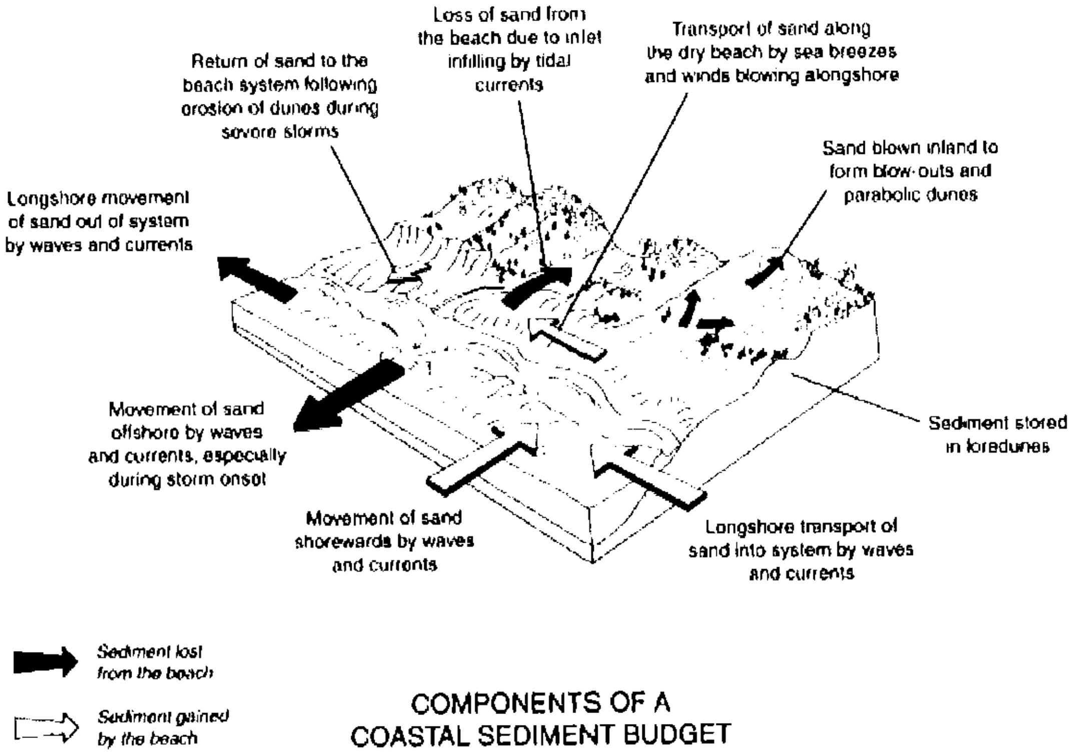
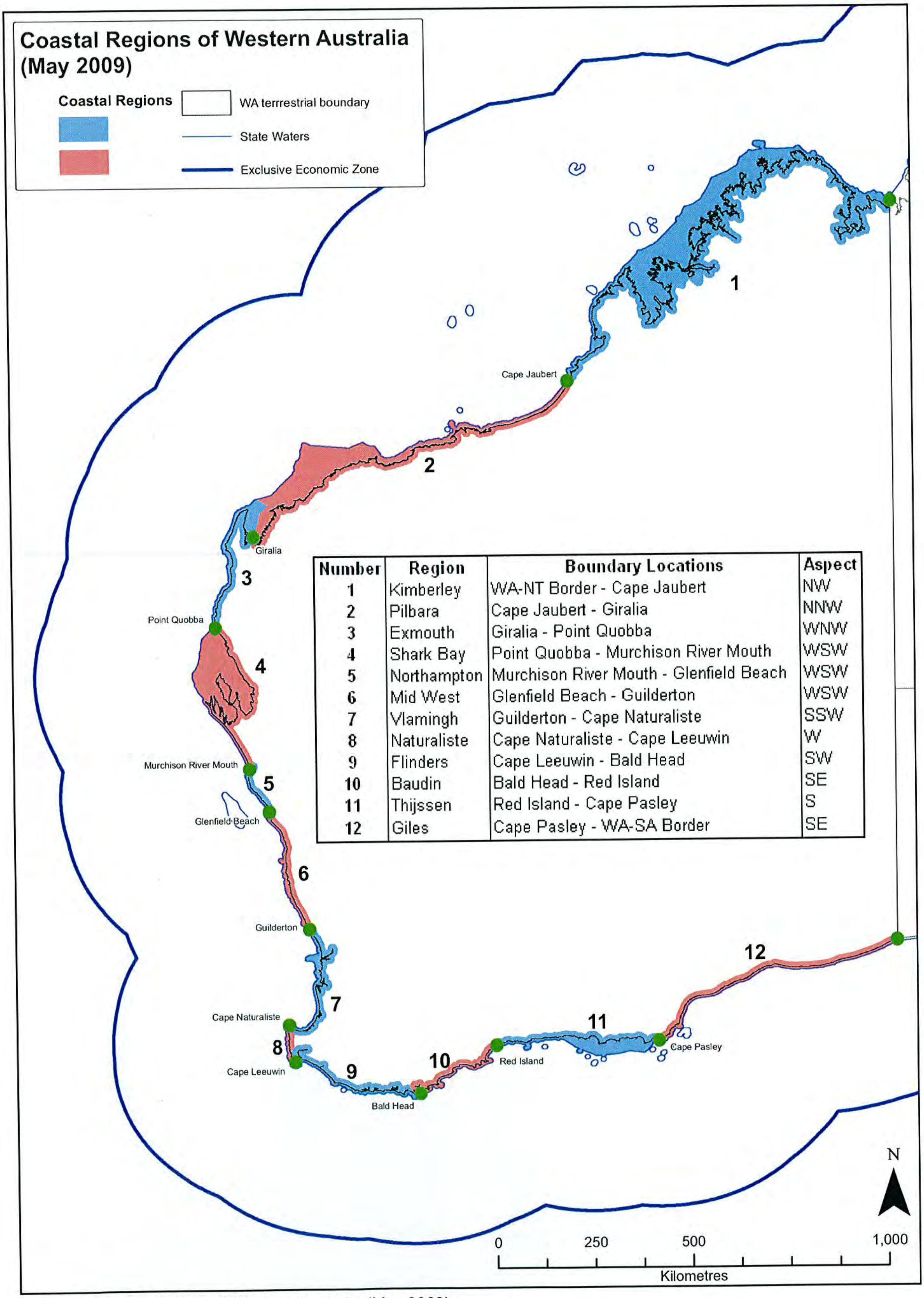


Figure 3 **Components of a Coastal Sediment Budget**

Sources of sediment include areas of bioproduction such as seagrass banks, rock platforms and mangals as well as the reworking of older sediments by coastal erosion of cliffs and dunes: transport paths include the dry beach surface as well as littoral drift and nearshore current patterns; and the sinks are active dunes, offshore sand banks and the tributaries of canyons crossing the inner continental shelf.



Number	Region	Boundary Locations	Aspect
1	Kimberley	WA-NT Border - Cape Jaubert	NW
2	Pilbara	Cape Jaubert - Giralia	NNW
3	Exmouth	Giralia - Point Quobba	WNW
4	Shark Bay	Point Quobba - Murchison River Mouth	WSW
5	Northampton	Murchison River Mouth - Glenfield Beach	WSW
6	Mid West	Glenfield Beach - Guilderton	WSW
7	Vlamingh	Guilderton - Cape Naturaliste	SSW
8	Naturaliste	Cape Naturaliste - Cape Leeuwin	W
9	Flinders	Cape Leeuwin - Bald Head	SW
10	Baudin	Bald Head - Red Island	SE
11	Thijssen	Red Island - Cape Pasley	S
12	Giles	Cape Pasley - WA-SA Border	SE

Figure 4: Coastal regions of Western Australia (May 2009)

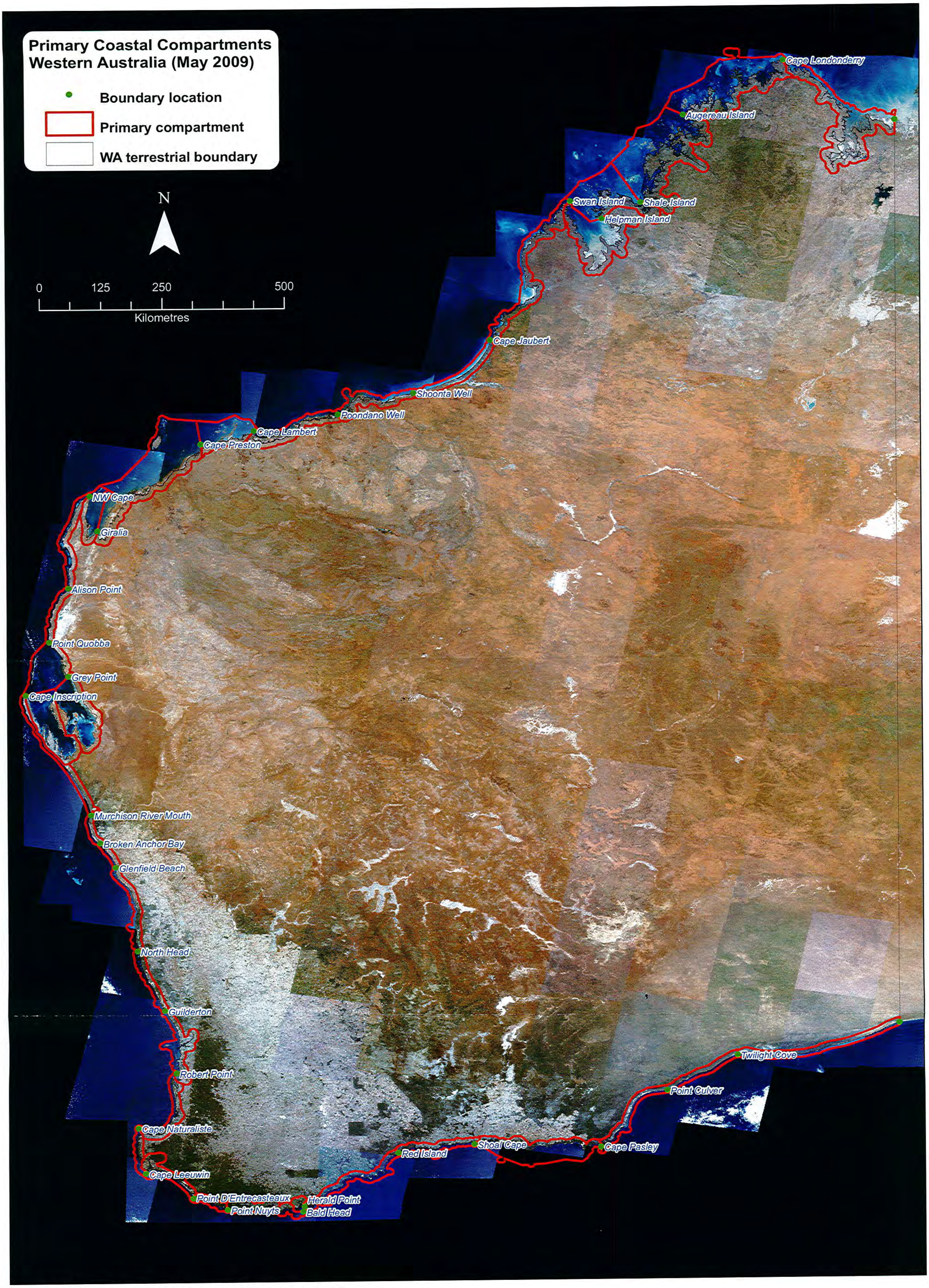


Figure 5: Primary coastal compartments of Western Australia

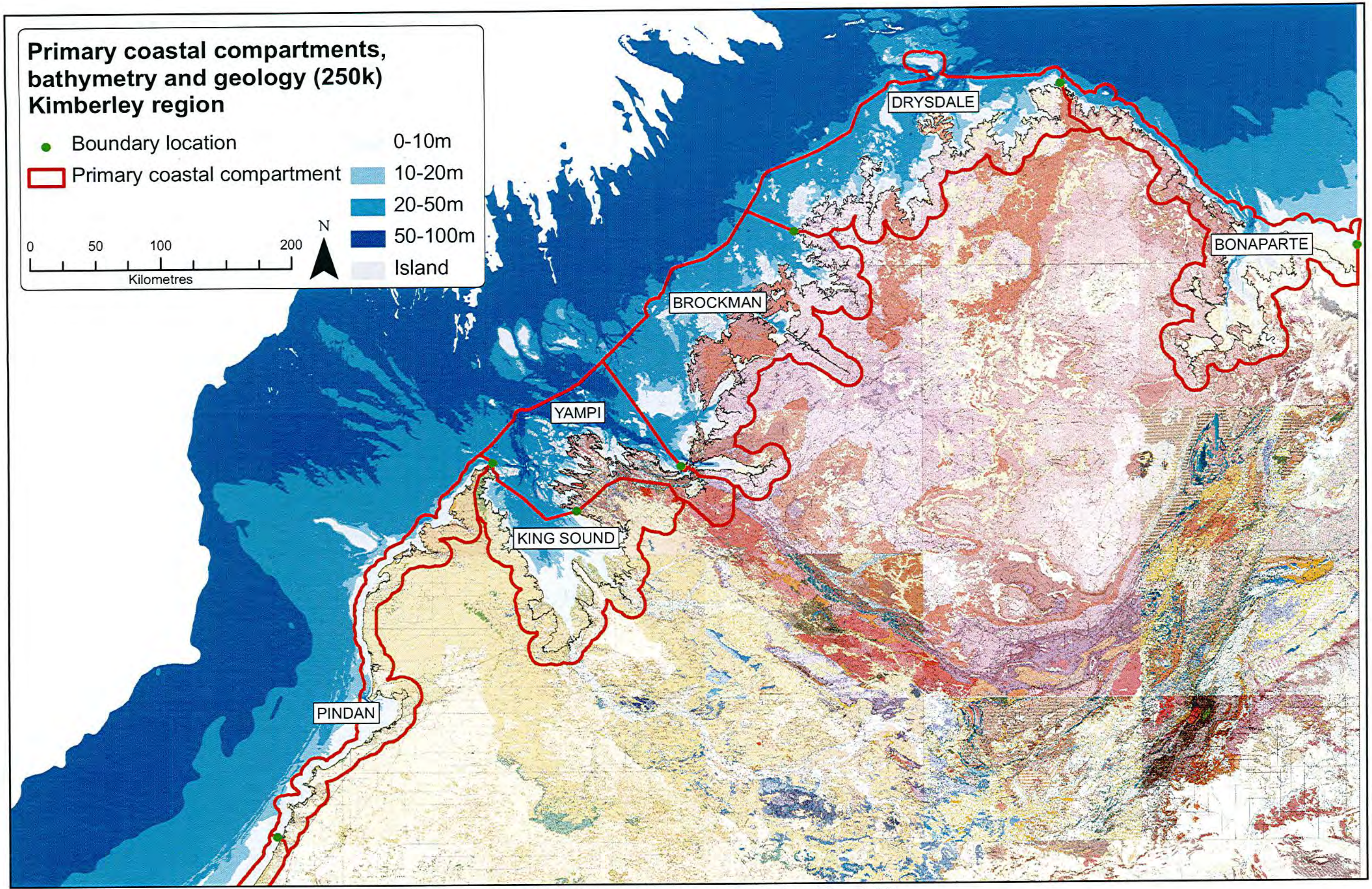


Figure 5a: Primary coastal compartments, bathymetry and 250K geology of the Kimberley coastal region (May 2009)

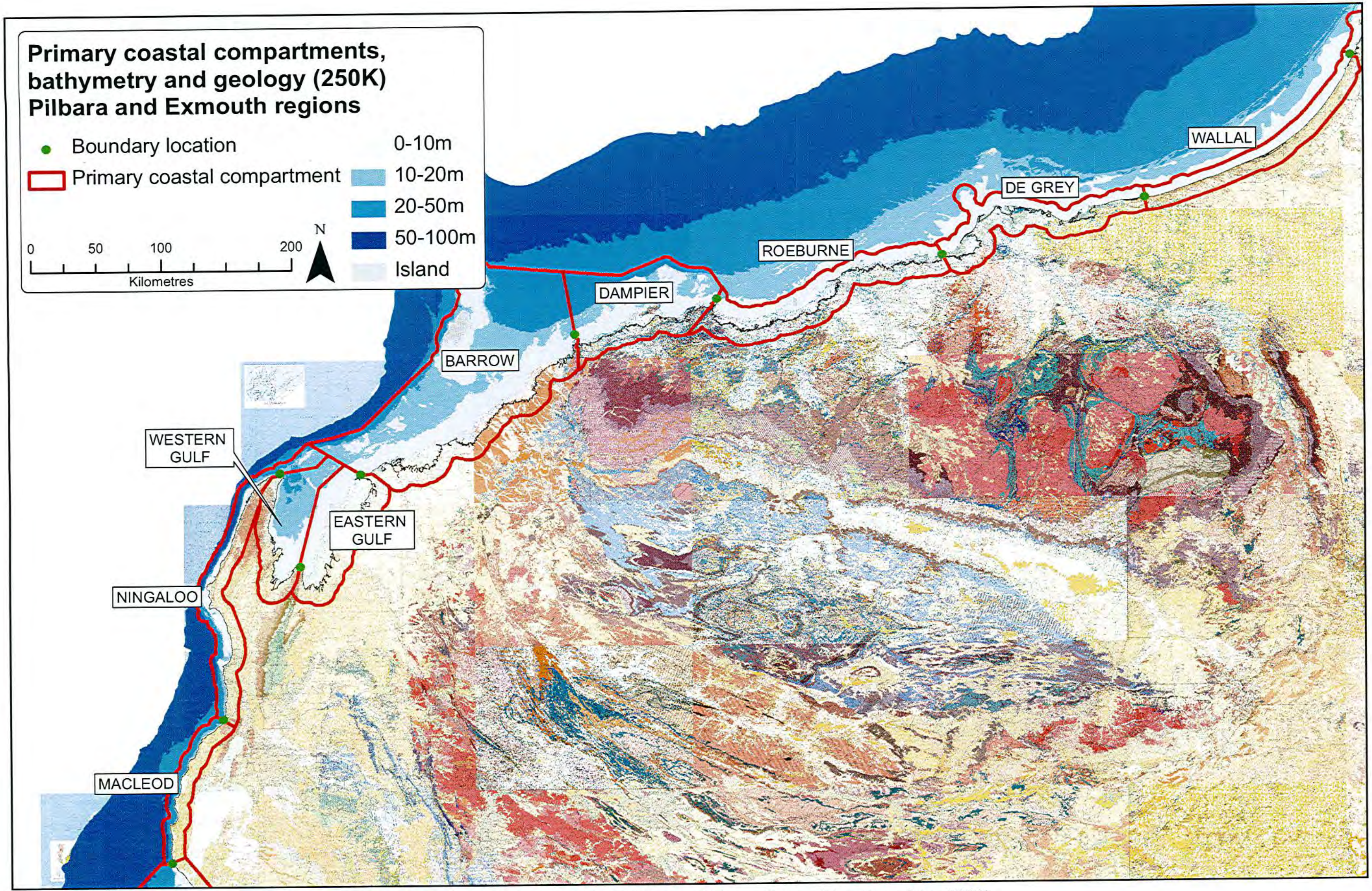


Figure 5b: Primary coastal compartments, bathymetry and 250K geology of the Pilbara and Exmouth coastal regions (May 2009)

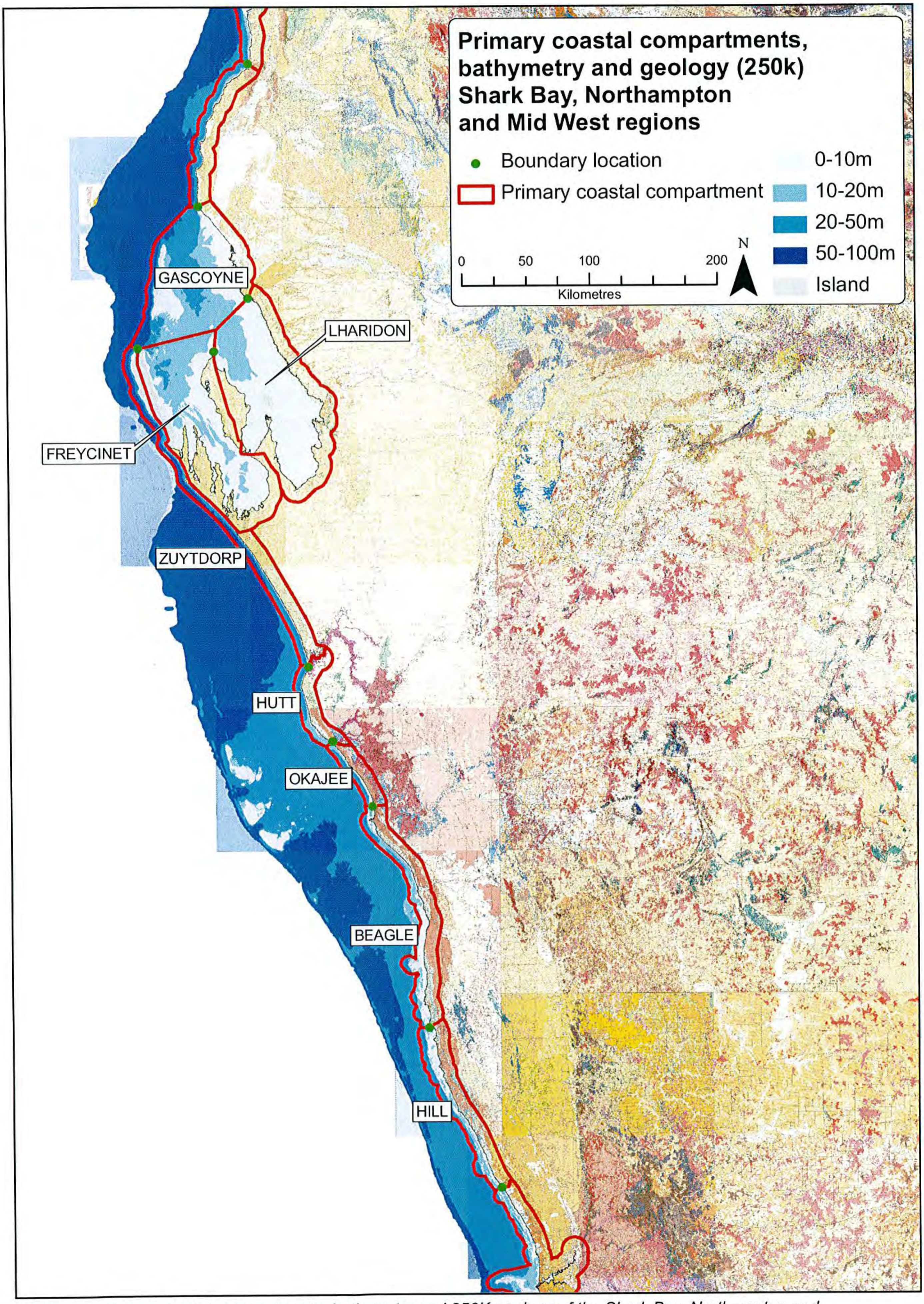


Figure 5c: Primary coastal compartments, bathymetry and 250K geology of the Shark Bay, Northampton and Mid West coastal regions (May 2009)

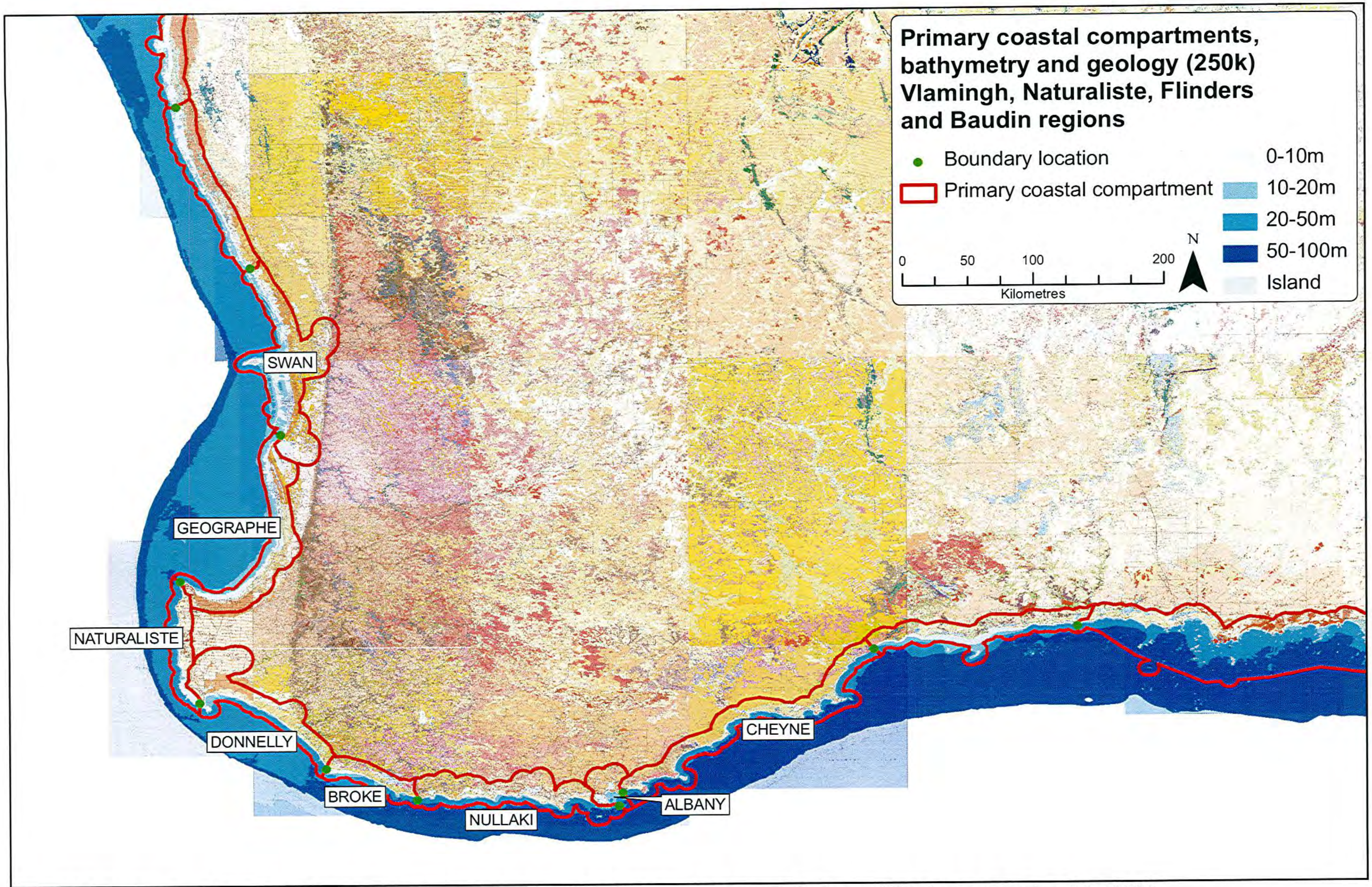


Figure 5d: Primary coastal compartments, bathymetry and 250K geology of the Vlamingh, Naturaliste, Flinders and Baudin coastal regions (May 2009)

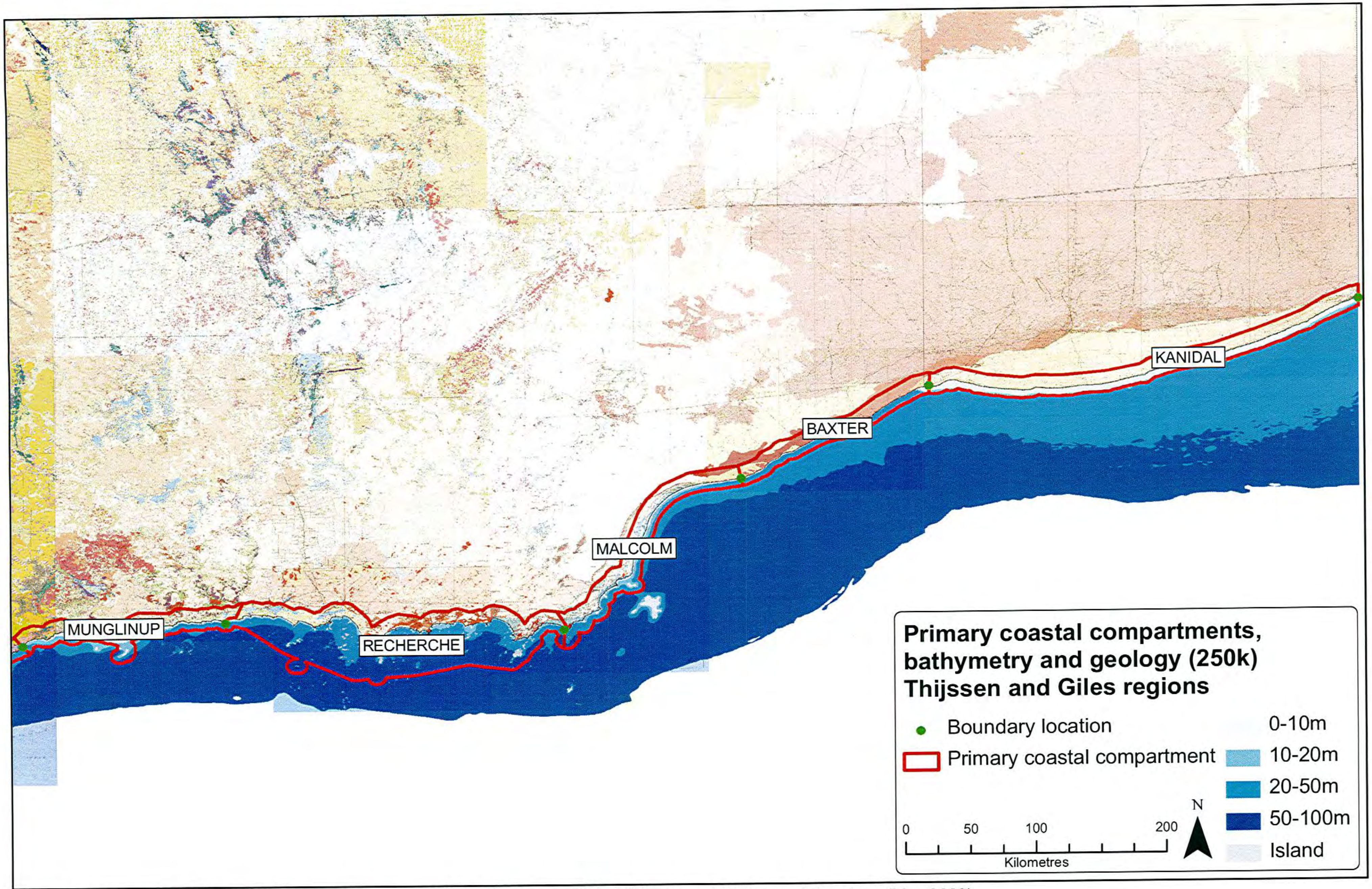


Figure 5e: Primary coastal compartments, bathymetry and 250K geology of the Thijssen and Giles coastal regions (May 2009)

Table 3. Primary compartments: 1. Region, boundary character and location.

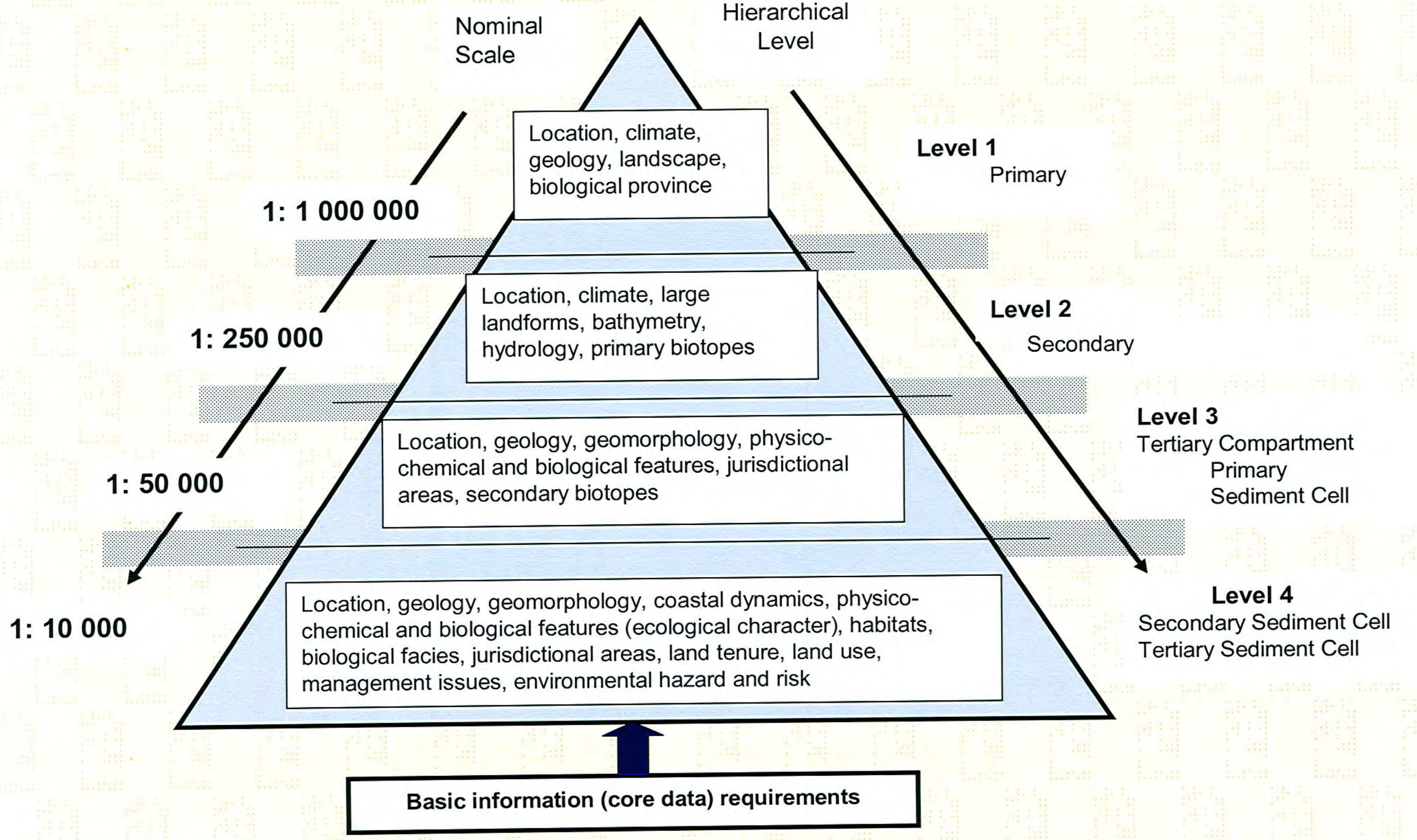
	Region	Primary Boundary	Boundary Characteristics (Divide From)	Latitude	Longitude
1	Kimberley	WA-NT Border	WA-NT Border: approximate divide between small and large tidal creeks	-32.26907500	126.03634167
2	Kimberley	Cape Londonderry	Geologic boundary & major change in aspect NE to NW	-14.87786111	129.00000000
3	Kimberley	Augereau Island	Geologic feature on N side of large embayments facing NW; change in aspect	-13.73939776	126.96074575
4	Kimberley	Shale Island	Central part of geological feature separating Walcott Inlet & Secure Bay	-14.75515567	125.12443296
5	Kimberley	Helpman Island	Change from bedrock to sedimentary coast with extensive sand/mud flats	-16.38231944	124.34095833
6	Kimberley	Swan Island	Major change in aspect from E to W facing coast	-16.68863474	123.62328487
7	Pilbara	Cape Jaubert	Northern start of 80 Mile Beach	-16.35123333	123.04573333
8	Pilbara	Shoonta Well	Low amplitude salient; change in aspect from WNW to N	-18.94000992	121.55579983
9	Pilbara	Poondano Well	Geomorphologic feature: divide separating coastal embayments & river catchments	-19.91290089	120.13340838
10	Pilbara	Cape Lambert	Rocky headland on a large cape; aspect change from NE to WNW	-20.29807341	118.73669472
11	Pilbara	Cape Preston	Rocky headland on a large cape separates N & NW facing embayments	-20.59246441	117.18459355
12	Pilbara	Locker Point	Chenier salient separating WNW from NNW facing shore & sheltering extensive mudflats	-20.83243470	116.20603286
13	Exmouth	Giralia	Major break between northern tide & southern wave dominated coast	-21.79899167	114.72275278
14	Exmouth	NW Cape	Major change in aspect from E to W facing coast	-22.43488846	114.30414878
15	Exmouth	Alison Point	Change in geology & aspect from W to NW facing shore; reef close to shore at S end	-21.78525556	114.16518611
16	Shark Bay	Point Quobba	Change in aspect from W to SW; landforms change from rocky to sandy coast	-23.49383816	113.76612275
17	Shark Bay	Grey Point	Geologic feature: Southern end of Gascoyne - Boodalia Delta complex. Hard to soft coast	-25.13097703	113.75174082
18	Shark Bay	Cape Peron North	Geologic promontory: Aspect changes from NE to NW facing shores	-24.49065556	113.40783889
19	Shark Bay	Cape Inscription	N end of Dirk Hartog Island; W shore of Bernier Island	-25.50385556	113.51057222
20	Northampton	Murchison River Mouth	Mouth of the Murchison River. Coastal aspect changes to WNW	-25.47953225	112.97116595
21	Northampton	Broken Anchor Bay	Change in coastal orientation SW to WSW	-27.70860000	114.15810833
22	Mid West	Glenfield Beach	Geologic change in offshore reef structure; change in dune landforms including Point Moore tombolo	-28.23164633	114.32179524
23	Mid West	North Head	Tombolo at S end of WSW facing rocky coast with salients and embayments	-28.68487436	114.60573468
24	Vlamingh	Guilderton	Mouth of the Moore River; change in orientation of coastal dunes	-30.23309013	114.99483304
25	Vlamingh	Robert Point	Geologic feature (Limestone) & southern limit of Rockingham foredune plain	-31.35398878	115.49937819
26	Naturaliste	Cape Naturaliste	Major geological promontory; aspect change from NE to W & WSW	-32.51960651	115.70203931
27	Fllinders	Cape Leeuwin	Major geological promontory; aspect change from SW to S	-33.53160388	115.00352606
28	Fllinders	Point D'Entrecasteaux	Limestone promomtory & cliffed coast separating large zeta-form embayments	-34.37697203	115.13590193
29	Fllinders	Point Nuyts	Geological promontory: aspect changes SW to SE	-34.84270038	116.00259771
30	Baudin	Bald Head	Geological promontory separates south coast from embayments; aspect change	-35.06047416	116.63039582
31	Baudin	Herald Point	Granite headland; aspect changes from SSW to SSE	-35.10823082	118.02130124
32	Thijssen	Red Island	Granite salient at divide between SE and S facing coast	-35.01548759	118.04677299
33	Thijssen	Shoal Cape	Granite promontory separating shallow SSE and SSW facing embayments	-34.02865445	119.77571759
34	Giles	Cape Pasley	Granite headland; Aspect changes from S to ESE. End of higher granitic coast with S aspect	-33.87760501	121.17714537
35	Giles	Point Culver	Low amplitude salient in limestone cliffs; aspect changes from ESE to SE	-33.94259605	123.51200258
36	Giles	Twilight Cove	Change in geology & landforms from limestone cliffs to sandy beaches; aspect SE to S	-32.90028973	124.73766583
37	Giles	WA-SA Border	Jurisdictional boundary; approximately coincidental with E end sandy Roe Plains & start of Nullabor Cliffs	-31.68782222	129.00000000

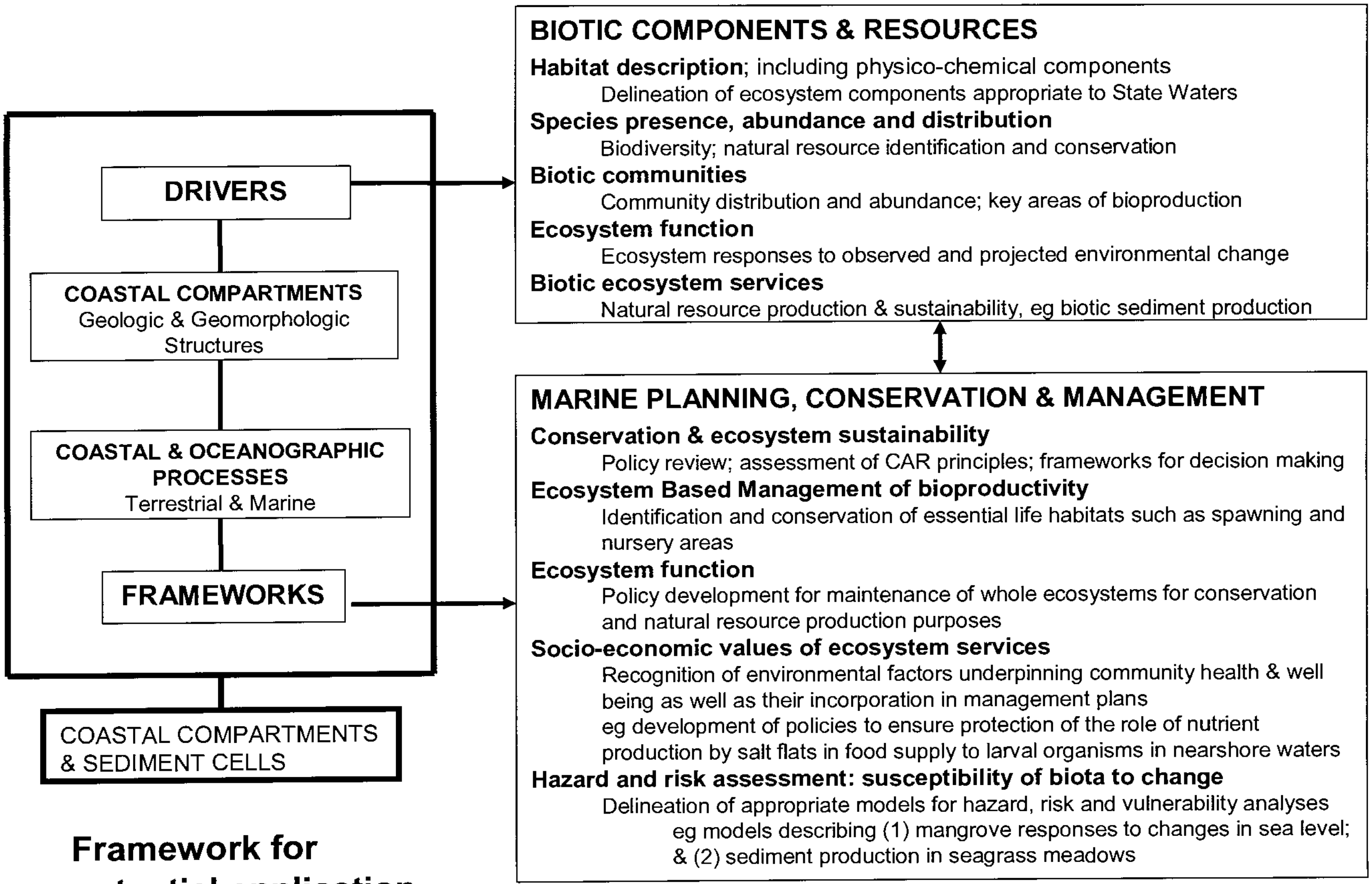
Table 4. Primary compartments: 2.geology, morphology, aspect, OSRA description, and Smartline geology

PRIMARY COMPARTMENT	GEOLOGY	LANDFORMS	ASPECT	%	OSRA - landform	Smartline - geology
BONAPARTE	SE Phanerozoic Browse basin, Phanerozoic Bonaparte basin	SE mud flats, Ord River delta, sandstone cliffs	NE	51	Broad, complex system of tidal channels and flats.	Dominantly sandstones with minor outcrops of basalt interbeds and volcaniclastic sequences.
	NW Proterozoic Kimberley basin			24	Beachrock & complex exposed resistant low cliffs with beach formation between headlands.	
DRYSDALE	Proterozoic Kimberley basin	ria coast, moderately deep embayments	NW	50	Complex, exposed, resistant low cliffs with beaches formed between headlands.	Dominantly sandstones with minor outcrops of undiff volcaniclastic sequences.
				28	Limited tidal flat development with some channels, may back onto low cliffs and sand ridges.	
BROCKMAN	Proterozoic Kimberley basin	deep embayments, fault aligned rivers	NW	69	Complex, exposed, resistant, low cliffs with beaches formed between headlands.	Dominantly sandstones with minor outcrops of undiff volcaniclastic sequences and lutite/arenite sequences.
				23	Tidal flat development with some channels.	
YAMPI	Proterozoic King Leopold orogen	highly irregular ria coast	NNW	39	Highly resistant and structurally controlled headlands; islands or drowned river valleys; all may show minor embayments with tidal flat or small flat development.	Dominantly sandstone with minor outcrops of dolerites, undiff lutite/arenite sequences and undiff granitoids.
				33	Tidal flat development with some channels.	
				22	Beachrock and adjacent barrier reeflines, with some beach formation between headlands	
KING SOUND	Phanerozoic Canning basin	King Sound, Fitzroy River delta	NNW	82	Broad, smooth, gently sloping beach with an extensive intertidal zone, backed by an extensive supratidal zone.	Dominantly sandstone with minor occurrences of undiff lutite/arenite sequences.
PINDAN	Phanerozoic Canning basin	irregular coast, S broad embayments	WNW	50	Complex system of tidal channels and flats. Broad, smooth, gently sloping beaches with an extensive intertidal zone.	Dominantly sandstone with minor occurrences of undiff lutite/arenite sequences.
				37	Minor tidal flat development with narrow sandy or silty beaches with a high tide range which may back onto low cliffs and sand ridges.	
WALLAL	Phanerozoic Canning basin	arcuate beaches and dunes	NW	96	Broad smooth gently sloping beach with an extensive intertidal zone, which may be backed by an extensive supratidal zone.	Northern section dominated by undiff lutite /arenite sequences. Southern section is dominantly sandstone.
DE GREY	E Phanerozoic Carnarvon basin	De Grey River delta	NNW	58	Broad smooth gently sloping beach with an extensive intertidal zone, which may be backed by an extensive supratidal zone.	Northern section is dominantly sandstone. Southern section is dominated by undiff granitoids.
				30	Limited tidal flat development with some channels, may back onto low cliffs and sand ridges	
ROEBURNE	Archaean - Paleoproterozoic Pilbara craton	rocky headlands and embayments	NNW	62	Complex system of tidal creek channels and flats with relict sandy beaches between headlands.	Dominantly undiff granitoids. Southern end has occurrences of metamorphosed basalts and banded-iron formation rocks.
				19	Broad smooth gently sloping beach with an extensive intertidal zone, which may be backed by an extensive supratidal zone.	
DAMPIER	Archaean - Paleoproterozoic Pilbara craton	rocky headlands and embayments, Dampier archipelago	NNW	79	Complex system of tidal creek channels and flats with relict sandy beaches between headlands.	Long sections of undiff granitoids interspersed with headlands of medium igneous rocks, basalts, volcaniclastic sequences, gabbro, and banded-iron formations.
				11	Highly resistant and structurally controlled headlands; islands or drowned river valleys; all may show minor embayments with tidal flat or small flat development.	
BARROW	Phanerozoic Carnarvon basin	river deltas and flood plains	NW	57	Broad complex system of tidal channels and flats.	Dominantly undiff lutites (siltstones, mudstones) with the northern headland consisting of undiff volcaniclastic sequences and banded-iron formations.
				25	Tidal flat development is variable, with some sandy and or fine grained beach material and is controlled by protection from offshore and onshore reef systems.	
EASTERN GULF	Phanerozoic Carnarvon basin	outwash plain	NNW	86	Broad complex system of tidal channels and flats.	Dominantly undiff limestones, with minor undiff lutites (siltstones, mudstones) at the northern end.
WESTERN GULF	Phanerozoic Carnarvon basin	beaches and dunes		62	Broad complex system of tidal channels and flats; some with complex relict sandy beaches; may back onto low cliffs and sand ridges.	Dominantly undiff limestones with minor outcrops of aeolian
				38	Narrow sandy or silty beach with a high tide range, may be marked by chenniers, beach ridges or low cliffs.	
NINGALOO	Phanerozoic Carnarvon basin	fringing coral reefs	W	79	Tidal flat development is variable, with some sandy and or fine grained beach material and is controlled by protection from offshore and onshore reef systems.	Dominantly undiff limestones with minor outcrops of aeolian calcarenite limestone at the southern end.
MACLEOD	Phanerozoic Carnarvon basin	fringing reefs	WNW	71	Beachrock dominates with some sandy sections between headlands; may have a low undercut beachrock cliff face.	Dominantly undiff limestones.
				23	Major tidal creek channels with complex relict sandy beaches, some tidal flat development between headlands.	

PRIMARY COMPARTMENT	GEOLOGY	LANDFORMS	ASPECT	%	OSRA - landform	Smartline - geology
GASCOYNE	Phanerozoic Carnarvon basin	beaches and dunes, Gascoyne River delta	WSW	45	Limited tidal flat development with some channels, may back onto low cliffs and sand ridges.	Undiff limestones.
LHARIDON	Phanerozoic Carnarvon basin	gulf	NW	41	Narrow sandy beach with extensive beachrock.	Undiff limestones.
				40	Variable tidal flat development; with some sandy beach material controlled by protection from offshore and onshore reef systems.	
FREYCINET	Phanerozoic Carnarvon basin	gulf	NW	98	Narrow sandy beach with extensive beachrock.	Undiff limestones.
ZUYTDORP	Phanerozoic Carnarvon basin	limestone cliffs	SW	92	Undercut steep cliff face eroding cainozoic sedimentary material.	Undiff limestones.
				8	Variable width sandy beach in association with resistant headlands; may include beachrock as low cliffs or headlands.	
HUTT	Phanerozoic Carnarvon basin	beaches and dunes	SW	68	Narrow sandy beach with extensive beach rock; backed by continuous stable well vegetated high dunes and/or low bluffs (<50m).	Dominantly sandstones.
				25	Broad smooth gently sloping coarse grained sandy beach, sometimes formed between resistant headlands; some active dunes and unstable blowout areas.	
OKAJEE	Proterozoic Northampton complex	beaches and dunes, Abrolhos Islands	SW	65	Variable width sandy beach without extensive beachrock, some as low cliffs or headlands; some backed by continuous stable well vegetated high dunes which may include calcarenite.	Dominantly lutites (siltstones, mudstones) undiff.
				21	Exposed high energy shorlines with eroded igneous or metamorphic rocks associated with overlying beachrock or aeolian limestone.	
BEAGLE	Phanerozoic Perth basin	offshore limestone reefs, tombolos, beaches and dunes	W	41	Broad smooth sloping sandy beach with well vegetated primary dune, often backed by parallel beach ridges or stabilised parabolic dunes.	Aeolian calcarenite limestone at northern end. Otherwise dominantly sandstones with minor occurrences of lutite/arenite sequences undiff.
				18	Beachrock dominates beach with occasional sandy sections; may have a low undercut beachrock cliff face	
				17	Broad smooth gently sloping coarse grained sandy beach with some active dunes and unstable blowout areas	
				13	Variable width sandy beach formed in areas protected by offshore reefs; may include some beachrock as low cliffs or headlands	
HILL	Phanerozoic Perth basin	offshore limestone reefs, tombolos, beaches and dunes	SW	32	Broad smooth gently sloping coarse grained sandy beach with some active dunes and unstable blowout areas.	Southern section dominated by calcareous lutites. Otherwise sandstones interspersed with lutites (sandstones, mudstones).
				28	Broad smooth sloping sandy beach with well vegetated primary dune, often backed by parallel beach ridges or stabilised parabolic dunes.	
				17	Variable width sandy beach formed in areas protected by offshore reefs; may include some beachrock as low cliffs or headlands.	
				10	Narrow sandy beach without extensive beachrock backed by continuous stable well vegetated high dunes which may include calcarenite.	
SWAN	Phanerozoic Perth basin	offshore limestone reefs, tombolos, beaches and dunes	WSW	65	Broad smooth sloping sandy beach with well vegetated primary dune, often backed by parallel beach ridges or stabilised parabolic dunes.	Calcareous lutites with minor lutite/arenite sequences. Aeolian calcarenite limestones, central to and north of the Swan River.
				19	Broad smooth gently sloping coarse grained sandy beach with some active dunes and unstable blowout areas.	
				10	Variable width sandy beach formed in areas protected by offshore reefs; may include some beachrock as low cliffs or headlands.	
GEOGRAPHE	Phanerozoic Perth basin, Leeuwin complex	tombolos, beaches and dunes, coastal lagoons	NW	42	Broad, smooth gently sloping coarse grained sandy beach with low primary dune, showing extensive vegetation; including barrier beaches and may include marshes, swamps or echelon lake systems in swales.	Dominantly lutite/arenite sequences undiff with minor occurrences of aeolian calcarenite limestones. Gneisses/migmatites/high grade
				24	Broad smooth gently sloping coarse grained sandy beach with some active dunes and unstable blowout areas.	
				13	Broad smooth sloping sandy beach with well vegetated primary dune, often backed by parallel beach ridges or stabilised parabolic dunes.	
NATURALISTE	Proterozoic Leeuwin complex	cliffs, headlands and bays	W	75	Exposed high energy shorlines with eroded igneous or metamorphic rocks associated with overlying beachrock or aeolian limestone.	Gneisses/ in vicinity of Cape Naturaliste migmatites/high grade metamorphics. Otherwise aeolian calcarenite limestone interspersed with granitoids undiff.
				11	Broad smooth gently sloping coarse grained sandy beach with some active dunes and unstable blowout areas.	

PRIMARY COMPARTMENT	GEOLOGY	LANDFORMS	ASPECT	%	OSRA - landform	Smartline - geology
DONNELLY	Phanerozoic Perth basin	beaches and dunes	SW	79	Broad smooth gently sloping coarse grained sandy beach with some active dunes and unstable blowout areas.	Dominantly lutite/arenite sequences; with 'gneisses, migmatites, grade metamorphics' and amphibolites in the vicinity of Point D'Entrecasteaux
				17	Narrow sandy beach without extensive beachrock backed by continuous stable well vegetated high dunes which may include calcarenite.	
BROKE	Proterozoic Albany - Fraser orogen	headlands, zeta formed bays	SSW	76	Exposed high energy shorlines with eroded igneous or metamorphic rocks associated with overlying beachrock or aeolean limestone.	Dominantly granitoids (some metamorphosed); minor gneisses/migmatites/high grade metamorphics.
				17	Variable width sandy beach formed in areas protected by offshore reefs; may include some beachrock as low cliffs or headlands.	
NULLAKI	Proterozoic Albany - Fraser orogen	headlands, zeta formed bays, estuaries	S	42	Exposed high energy shorlines with eroded igneous or metamorphic rocks associated with overlying beachrock or aeolean limestone.	Granitoids undiff interspersed with gneisses/migmatites/ high
				38	Broad smooth curving sandy beach, which may be cuspate or crenulate, formed between or in association with resistant headlands.	
				20	Narrow to wide sandy beach seaward of low bluffs (< 50m), in sedimentary rock including limestone.	
ALBANY	Proterozoic Albany - Fraser orogen	gulf	E	75	Broad smooth sloping sandy beach with well vegetated primary dune, often backed by parallel beach ridges or stabilised parabolic dunes; some beaches have formed between or in association with resistant headlands.	Granitoids/metamorphosed granitoids interspersed with gneisses/migmatites/ high grade metamorphics.
				25	Exposed high energy shorlines with eroded igneous or metamorphic rocks associated with overlying beachrock or aeolean limestone.	
CHEYNE	Proterozoic Albany - Fraser orogen	headlands, zeta formed bays	SE	49	Exposed high energy shorlines with eroded igneous or metamorphic rocks associated with overlying beachrock or aeolean limestone.	Dominantly metamorphosed granitoids (and minor undiff) with minor sections of spongolite (in lutite/arenite sequences).
				33	Broad smooth curving sandy beach, which may be cuspate or crenulate, formed between or in association with resistant headlands; some backed by active dunes and unstable blowout areas	
MUNGLINUP	Proterozoic Albany - Fraser orogen	limestone coast	SSE	39	Broad smooth curving sandy beach, which may be cuspate or crenulate, formed between or in association with resistant headlands.	Dominantly metamorphosed granitoids with minor occurrences of aeolian calcarenite limestone at the western end. Interbedded quartzites and schists occur in proximity to Red island.
				31	Variable width sandy beach formed in areas protected by offshore reefs; some with extensive beachrock; may include some beachrock as low cliffs or headlands.	
				27	Exposed high energy shorlines with eroded igneous or metamorphic rocks associated with overlying beachrock or aeolean limestone.	
RECHERCHE	Proterozoic Albany - Fraser orogen	rocky coast, zeta formed bays, tombolos	S	41	Broad smooth curving sandy beach, which may be cuspate or crenulate, formed between or in association with resistant headlands.	Dominantly granitoids undiff or metamorphosed granitoids with with minor spongolite (in lutite/arenite sequences).
				41	Exposed high energy shorlines with eroded igneous or metamorphic rocks associated with overlying beachrock or aeolean limestone.	
MALCOLM	Proterozoic Albany - Fraser orogen	beaches and dunes, limestone cliffs	SE	46	Broad smooth sloping sandy beach with well vegetated primary dune, often backed by parallel beach ridges or stabilised parabolic dunes.	Granitoids (metamorphosed and undiff) in central section. Schists/quartzites/gneisses in proximity to Point Culver.
				30	Broad smooth gently sloping coarse grained sandy beach with some active dunes and unstable blowout areas.	Limestone undiff in proximity to Twilight Cove.
				16	Exposed high energy shorlines with eroded igneous or metamorphic rocks associated with overlying beachrock or aeolean limestone.	
BAXTER	Phanerozoic Eucla basin	limestone cliffs	SE	100	Undercut steep cliff face eroding cainozoic sedimentary material.	Limestones undiff
KANIDAL	Phanerozoic Eucla basin	limestone platform reefs, beaches and dunes	SSE	52	Variable width sandy beach formed in areas protected by offshore reefs; may include some beachrock as low cliffs or headlands.	Limestones undiff
				28	Broad smooth gently sloping coarse grained sandy beach backed by vegetated dunes, some active; may include marshes, swamps or echelon lake systems in swales.	
				14	Beachrock dominates beach with occasional sandy sections; may have a low underct beachrock cliff face.	


Nominal Scale
Hierarchical Level
Location, climate, geology, landscape, biological province
1: 1 000 000
Level 1
Primary
Location, climate, large landforms, bathymetry, hydrology, primary biotopes
1: 250 000
Level 2
Secondary
Location, geology, geomorphology, physico-chemical and biological features, jurisdictional areas, secondary biotopes
1: 50 000
Level 3
Tertiary Compartment
Primary Sediment Cell
Location, geology, geomorphology, coastal dynamics, physico-chemical and biological features (ecological character), habitats, biological facies, jurisdictional areas, land tenure, land use, management issues, environmental hazard and risk
1: 10 000
Level 4
Secondary Sediment Cell
Tertiary Sediment Cell
Basic information (core data) requirements



Framework for potential application