3. Review and Synthesis of Literature for the North West Marine Region

3.1. THE NORTH WEST MARINE REGION

3.1.1. Introduction

The tectonic history, oceanography, late Quaternary evolution and surficial sedimentology of the North West Marine Region (NWMR) have been the focus of extensive research by various authors and government agencies at different temporal and spatial scales. The North West Margin[1] is a tropical carbonate margin and has been since the Eocene (~56 Ma). The NWMR region includes notable geomorphic features and covers an extensive area of shelf, slope and abyssal plain/deep ocean floor. Geoscience Australia has contributed extensively to the study of the region and has published records on the North West Shelf (Exon, 1994; Exon and Colwell, 1994; Jones, 1973), Timor Sea (van Andel and Veevers, 1967), Sahul Shoals (Marshall et al., 1994), Exmouth Plateau (Stagg et al., 2004), Scott Plateau and Rowley Terrace (Ramsay and Exon, 1994; Stagg and Exon, 1981), Carnavorn Terrace (Heggie et al., 1993), Wallaby Plateau (Sayers et al., 2002) and Argo Abyssal Plain (Buffler, 1994). Key geomorphic features and provinces of the NWMR have been mapped using a consistent bathymetric grid of Australia's EEZ (Heap and Harris, in press) and relevant scientific literature.

On the basis of relevant literature, the NWMR is divided into four physiographic regions: the inner shelf; middle shelf; outer shelf/slope; and abyssal plain/deep ocean floor (Fig 3.1). These divisions are made on the basis of water depth and the geomorphic provinces described in a recent study on the geomorphology of the Australian margin (Heap and Harris, in press-b). The inner shelf is between ~ 0-30 m and is characterised by highly turbid water throughout the year. The outer shelf/slope region extends from ~ 200 m water depth to the base of the slope, as defined by Heap and Harris (in press), to where there is a general reduction in gradient to <1:1000 and water depths are >4,000m. The middle shelf is defined as the region between 30 and 200 m water depths. Rise occurs within the NWMR and because of its limited extent, it is not treated here as an exclusive physiographic division. Abyssal plain/deep ocean floor regions are defined as flat or gently sloping regions in abyssal depths greater than ~ 4,000 m (Heap and Harris, in press-b).

[1] 'North West Margin' has been used in petroleum publications to refer to the area of shelf and slope between Exmouth and the Bonaparte Gulf.

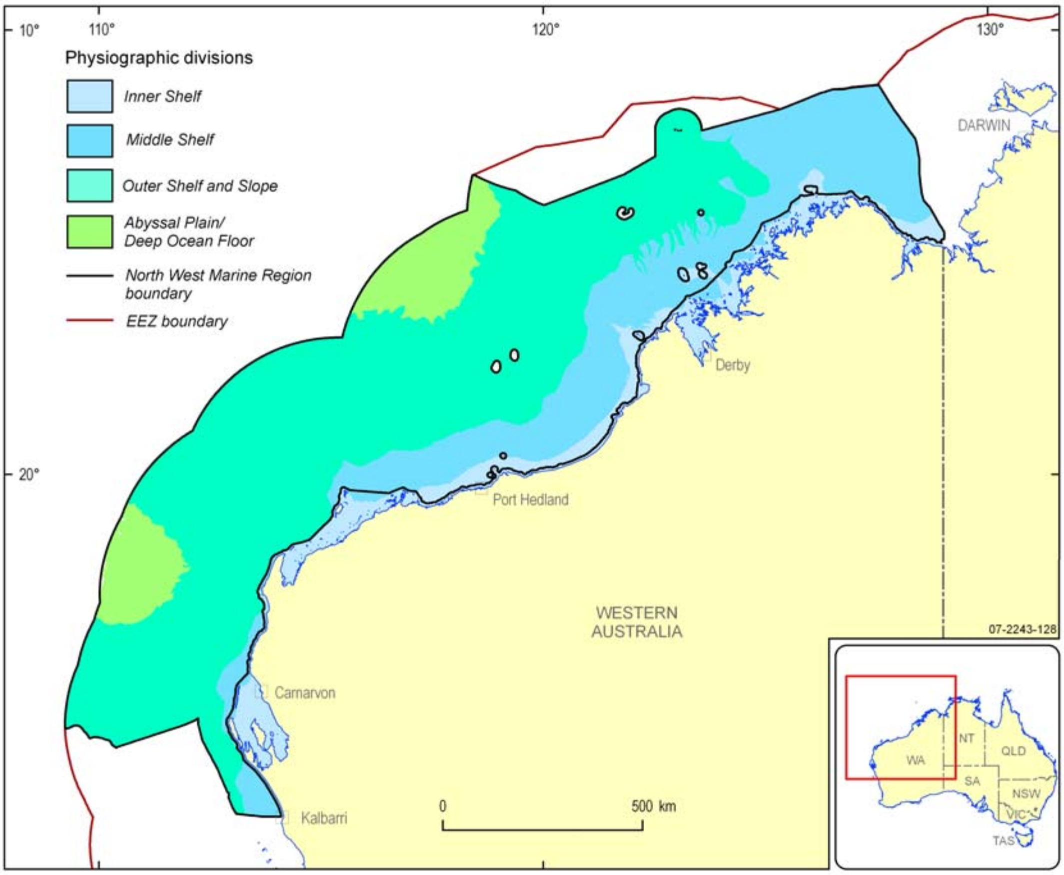

Figure 3.1. Physiographic division of the NWMR, including the inner, middle outer shelf/slope and abyssal plain/deep ocean floor.

3.1.2. Tectonic History

The continental margin of the NWMR has a complex tectonic history characterised by continental break-up, subsidence and deposition, fluvio-deltaic sedimentation, carbonate deposition, siliclastic deposition, thermal uplift and erosion, faulting, and a major period of rift volcanics (Exon and Colwell, 1994). Notable works have been complied by Geoscience Australia (Buffler, 1994; Colwell et al., 1994a; Colwell et al., 1994b; Exon, 1994; Gopala et al., 1994; Ramsay and Exon, 1994; Shafik, 1994; Stagg et al., 2004). A summary of key events and their implications for marine planning purposes is outlined below.

The Northwest Shelf, from Exmouth Gulf to Darwin (Purcell and Purcell, 1988), comprises four major Phanerozoic (550 Ma – present) sedimentary basins of up to 15 km in depth. These include the Bonaparte, Browse, offshore Canning and Carnavorn Basins (Exon, 1994). The outer Northwest Shelf formed as part of East Gondwana during the Palaeozoic (550 – 250 Ma) and subsided during the Late Palaeozoic to form the Westralian Basin on the southern margin of the Tethys Sea (Exon and Colwell, 1994). The superbasin filled with thick Triassic sediments (~235 – 200 Ma) and variable amounts of Jurassic (200 – 154 Ma) sediments before continental break up during the late Jurassic to early Cretaceous (~160 – 100 Ma).

Fluvio-deltaic sedimentation occurred during the late Triassic, and reefal carbonates were deposited on what is now the Exmouth Plateau and Rowley Terrace (Exon and Colwell, 1994). In the middle Jurassic (~175 Ma), before the northern Gondwana break-up, thermal uplift and erosion of the crust occurred and was followed by a period of major faulting and rift volcanism (Exon and Colwell, 1994). Seafloor spreading commenced in the Late Jurassic (~165-161 Ma) and formed the Argo Abyssal Plain and later the Cuvier Abyssal Plain in the Early Cretaceous (~140-136 Ma) (Falvey and Veevers, 1974). The Early Cretaceous break-up of Greater India and Australia controlled much of the development of Exmouth Plateau and Carnarvon Basin (Stagg et al., 1999). After the break-up, subsidence of the distal parts of the margin formed the Exmouth and Scott Plateaus and Rowley Terrace (Falvey and Veevers, 1974). The tectonic framework of the Exmouth Plateau was subsequently controlled by Mesozoic rifting and transform faulting from the break-up (Ramsay and Exon, 1994). A fore-bulge (uplift of the lithosphere) south of the Java Trench developed in the early Miocene (~32 Ma) and created a regional tilt to the south, resulting in north-east inclined faults (Exon and Colwell, 1994). Carbonate masses of rock (bioherms) composed of marine organisms, namely corals and algae, have since accumulated along the fore-bulge.

Tectonic history and basinal settings have controlled the platform morphology, stratigraphic features, depositional sequences, and distribution of the tropical carbonate northwest margin predominantly by maintaining low rates of siliclastic material transfer from the adjacent mainland (Bosence, 2005). Passive margin platforms, such as the Northwest Shelf, are major sites for calcium carbonate accumulation (Bosence, 2005). Following continental breakup of Gondwana, progradation of upper-Cretaceous and Cenozoic carbonates occurred on the outer shelf/slope due to subsidence and the creation of significant accommodation space (Branson, 1978; Exon et al., 1982). Reefs have continued to preferentially develop along the slightly raised rim of the outer shelf/slope (i.e., the Rowley Shoals, Ashmore, Seringapatam, and Scott Reefs).

3.1.3. Oceanography

The NWMR is subject to a variable and energetic oceanic regime that is characterised by the Indonesian Throughflow (ITF) (Gordon and Fine, 1996; Gordon, 2005; Potemra et al., 2003), the Leeuwin Current (LC) (Cresswell, 1991; Holloway, 1995; Holloway and Nye, 1985), internal tides, swell waves, large tides and monsoonal cyclones (Holloway, 1983a; Holloway, 1983b; Ribbe and Holloway, 2001). The ITF flows as a warm mass of saline water at 0.01 – 0.015 km^3s^{-1} that travels south between the Indonesian Archipelago and Australia in response to a steric height gradient in the Pacific (from CSIRO, 2004; Farrand, 1964) (Fig. 3.2.). The ITF impinges onto the Northwest Shelf and contributes to the initiation of the LC (Vranes et al., 2002). The LC is a warm ocean current that flows southwards down the Western Australia coast to Cape Leeuwin where it turns east and travels into the Great Australian Bight (Peter et al., 2005) (Fig.3.2). The LC flow is unlike most eastern boundary currents as it flows in a southerly direction against the dominant wind direction (Godfrey and Ridgway, 1985). The flow is strongest south of North West Cape, where the reduction in shelf width concentrates and intensifies the flow (Holloway, 1995).

The Northwest Shelf is a region characterised by semi-diurnal tides with a spring tidal range that exceeds 6 m in some locations (Easton, 1970). The tidal range increases significantly in magnitude from the Dirk Hartog Shelf to the Sahul Shelf. Tides are <2 m on the inner Dirk

Hartog Shelf, (Nahas et al., 2005), 1.8 m in Exmouth, 2.1 m in Port Hedland, 8.5 m in Broome, 9.2 m in King Sound, and 10.5 m in Collier Bay (Harris et al., 1991; Jones, 1973). Tidal velocities are highest on the inner shelf, and internal tide that generate at the shelf edge during summer months when the water column stratifies move onshore as non-linear waves at speeds of 0.5-1m s^{-1} (Baines, 1981). The shelf bathymetry influences the cross shelf tidal amplification of the region due to an increase in the amplitude of the shelf edge. As the shelf widens and the offshore gradient becomes gentler, significant cross-shelf amplification of the semi-diurnal tide occurs (1.8 m at Exmouth and 9.2 m in King Sound) (Harris et al., 1991; Holloway, 1983b).

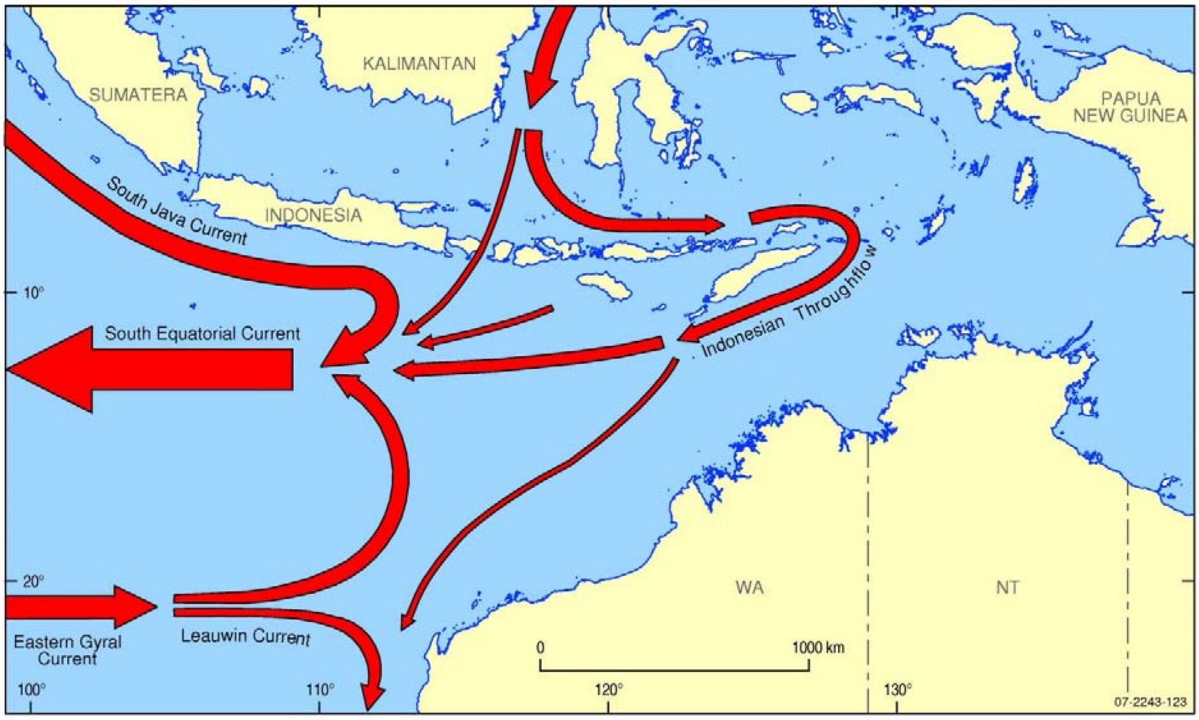

Figure 3.2. Major ocean currents that influence the NWMR (CSIRO, 2004).

The NWMR is an oligotrophic environment (Holloway et al., 1985). Nutrient enrichment of the shelf occurs through river runoff, tidal mixing, internal tides, low frequency circulation, upwelling, and tropical cyclones that induce oceanic mixing and further upwelling (Holloway et al., 1985). The LC maintains warm Sea Surface Temperatures (SST), that inhibit the establishment of macrophyte communities that compete with reef building organisms (Hatcher, 1991) and contribute to the transportation of reef larvae and propagules down the west coast of Australia (Peter et al., 2005). Recorded salinities attain 34.51‰ to 34.75‰ in the Timor Sea (Glenn, 2005), 34.6‰ at Exmouth Plateau (Holloway, 2001), and 35.2‰ to the south of Shark Bay (Woo et al., 2006). The salinity of the Dirk Hartog Shelf is slightly increased because of the transportation of saline water in the LC and the exit of hypersaline water from Shark Bay (Cresswell, 1991; Nahas et al., 2005).

The oceanography of the NWMR plays an important role in regulating sediment transport, deposition and erosion (James et al., 2004). Major contributors to sediment mobilisation include: storm events, including tropical cyclones; internal tides; and ocean currents, including the LC. Tropical cyclones are common in Northwest Australia and are significant agents in the initiation of sediment movement and deposition (Porter-Smith et al., 2004). Internal tides on the

Northwest Shelf lead to the re-suspension and net down-slope deposition of sediment (Ribbe and Holloway, 2001). The LC contributes significantly to the distribution of seabed sediments by transporting terrigenous sediments southwards (Gingele et al., 2001b) and maintaining low rates of nutrient delivery which allows the formation and survival of carbonate reefs south of North West Cape (Hatcher, 1991). Carbonate production on the Rowley Shelf is limited by the seaward flow of saline inner shelf coastal waters (James et al., 2004) (Fig. 3.3.).

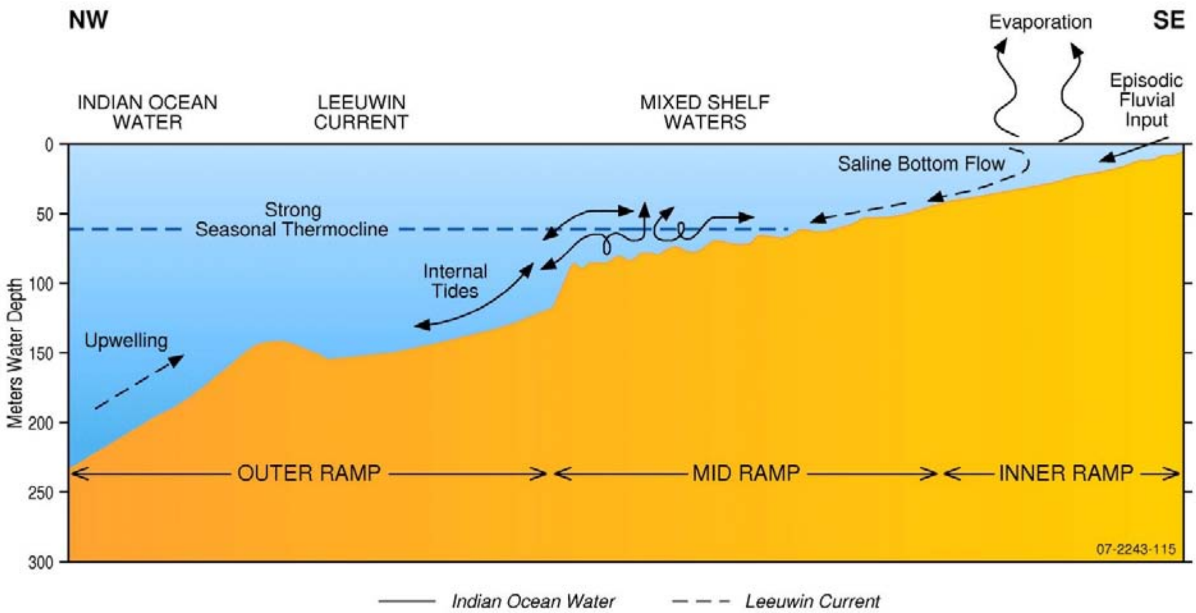

Figure 3.3. Summary diagram of the major oceanographic-climatic factors that affect sedimentation on the ramp that characterises the Northwest Shelf (James et al., 2004).

While oceanography places controls on sediment distribution, the morphological setting of the region impacts the oceanography. The narrowing of the shelf south of North West Cape increases and intensifies the LC, and the broad shelf north of North West Cape allows the propagation of large internal tides (Holloway, 1983a; Holloway, 1983b). A classification of the Australian shelf based on sediment threshold values has identified dominant areas of tide- and/or wave-induced sediment transport (Porter-Smith et al., 2004). The inner shelf area north of Dampier is either wave only or tidal dominated, the broad outer shelf north of Dampier tide only, and the shelf south of Dampier wave dominated (Fig. 3.4) (Porter-Smith et al., 2004).

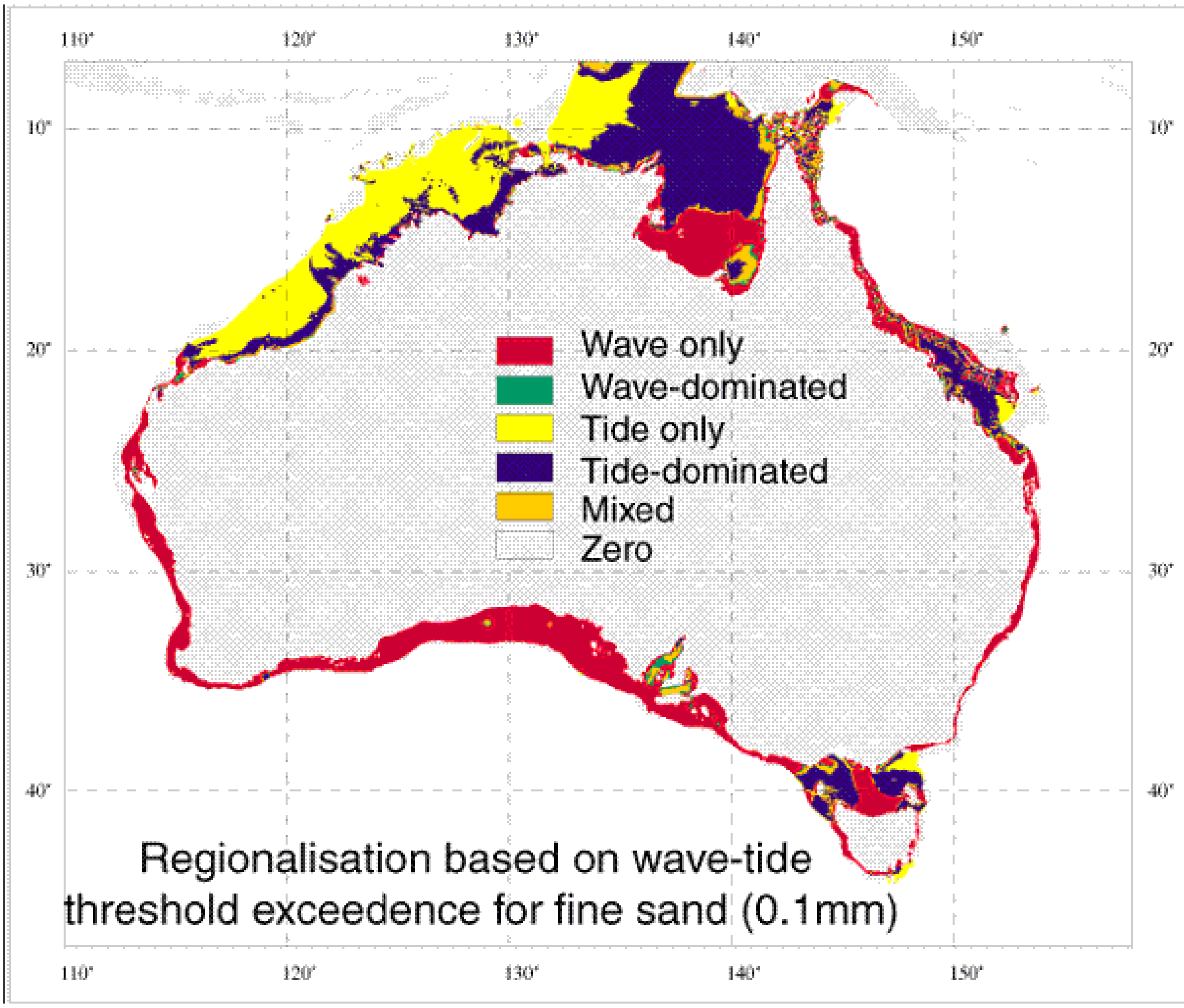

Figure 3.4. Regionalisation of the Australian continental shelf for fine sand (0.1mm) distribution calculated from wave and tide exceedence estimates (Porter-Smith et al., 2004).

3.1.4. Late Quaternary (Holocene) Evolution

The late Quaternary evolution of the NWMR is characterised by a fluctuating climate, oceanography and sea level, which is reflected in seabed sediments and geomorphic features of the region. During the Last Glacial Maximum (LGM) at around 20 ka BP, sea level was ~ 110-130 m lower than present (Harris et al., 1991; van Andel et al., 1967; Woodroffe, 2000). The shelf was sub-aerially exposed, arid, and covered with savannah vegetation (Fleming et al., 1998). SST's were lower, evaporation was reduced and the southward flowing LC weakened and/or arrested (Okada and Wells, 1997). Rapid sea level rise from 18 ka to 8 ka BP (Curray, 1961) and gradual rise thereafter submerged the shelf area until sea level reached its present elevation. These late Quaternary adjustments assisted in the growth and development of reef building organisms, left drowned terraces and steps along the outer shelf (at ~ 60, 65, 75, 190, 280, 360 m, and the most prominent at 120 m water depths) (Harris et al., 1991; Jones, 1973), and stranded carbonate sediments on the middle shelf (James et al., 2004).

During the LGM, the NWMR was subject to cooler SST's, climatic conditions and a weaker LC (van der Kaars, 1991; Wells and Wells, 1994). Large areas of anomalously cool water were widespread (Prell et al., 1980), and SST was reduced by 6-7°C off North West Cape (Wells et al., 1994). These cool sea surface temperatures and the associated strong offshore winds from Western Australia combined to create strong bottom upwelling (Okada and Wells, 1997) that resulted in increased surface productivity during the LGM (Wells et al., 1994). The volume and intensity of the LC decreased and/or ceased at the LGM and has subsequently increased during the non-glacial period (Gingele et al., 2001b). The increase in flow has subsequently prevented and/or limited oceanic upwelling and has contributed to low productivity levels in the region.

The distribution of seabed sediments in the NWMR reflects the late Quaternary evolution of the region. Shallow-water calcium carbonate production was active during the Pleistocene to early Holocene along much of the Northwest margin. Production on the shelf was dominated by ooids and smaller amounts of *Halimeda* but was unable to keep pace with the rising sea levels of the late Quaternary (Dix et al., 2005). As a result the sediments are currently localised to the mid shelf. The most prominent of these are ooids and peloids that formed at 15.4-12.7 ka BP in the saline waters of post glacial sea level rise (James et al., 2004). The initiation of the LC arrested ooid production and resulted in the accumulation of biofragmental benthic Holocene sediment that is now localised to the inner shelf and to a ridge of planktonic foraminifera offshore (James et al., 2004). Today, carbonate production is limited due to the strengthening of summer rains, increased volume of siliclastic input, and the initiation of the LC that occurred during the Holocene (Dix et al., 2005).

Modern coral reefs of the NWMR began as coral communities that formed substrata during the Holocene marine transgression (Hatcher, 1991). These include the Ningaloo and Ashmore Reefs (Fig. 3.12). Ashmore Reef is located at the shelf edge, and the Holocene section began growth at 7.5 ka BP in response to the changing ocean and climate conditions (Glenn and Collins, 2005). The following sequence of events, summarised from the model of Ashmore Reef growth (Glenn and O'Brien, 1999; Glenn and Collins, 2005), is considered to characterise regional Holocene development on the margin:

- 7.5-6.5 ka BP: reef growth began with an initial vertical growth phase that recolonised the underlying Pleistocene strata and kept pace with rising sea levels;
- 6.5-4.5 ka BP: a transitional phase of reef growth occurred as the reef caught pace with slowly rising sea levels; and
- 4.5 ka BP – to present: the reef extended laterally as the reef flats became more pronounced, wider and productive. Infilling of the reef lagoons occurred as mobile intertidal sand flats began to form.

The Ningaloo Reef is located on the inner shelf and similarly took on its present form during the Holocene. The Holocene section recolonised the last interglacial reef at North West Cape at 7.57 ka (Collins et al., 2003).

3.1.5. Geomorphology

The NWMR comprises an extensive array of geomorphic features and provinces and contains 19 of the 21 geomorphic identified for Australia’s EEZ (Heap and Harris, in press-b). Geomorphic features within the region and their coverage are summarised in Section 4. Prominent geomorphic features include the Exmouth Plateau (Stagg et al., 2004), Carnarvon Terrace (Heggie et al., 1993), Rowley Terrace (Stagg and Exon, 1981), Scott Plateau (Stagg, 1978), King Sound Basin (Semeniuk, 1980; Semeniuk, 1981; Semeniuk, 1982), Cuvier Abyssal Plain, Argo Abyssal Plain (Buffler, 1994), Ashmore Reef (Glenn and O'Brien, 1999; Glenn and Collins, 2005), Scott Reef, Rowley Shoals and Ningaloo Reef (Collins et al., 2003). Key geomorphic features and their place names are displayed in Figure 3.5 and Table 3.1.

A total of four shelf divisions are recognised within the region: Dirk Hartog, Rowley, Northwest, and Sahul Shelves (Harris et al., 2003; Heap and Harris, in press-b). The shelf width increases northwards and the broad Sahul Shelf extends continuously to Indonesia. At North West Cape, the Dirk Hartog Shelf reaches the minimum shelf width of the Australian continental margin at ~7 km. Two main abyssal plains/deep ocean floor features lie within the NWMR, and these extend well beyond the boundary of Australia's EEZ. An extensive series of carbonate banks and coral reefs are located within the NWMR. The outer Northwest Shelf is deposited with a string of submerged carbonate banks and these include the Ashmore Reef (Glenn and O'Brien, 1999; Glenn and Collins, 2005), Cartier Island and Seringapatam Reef. Reefs of the inner shelf are dominated by hard corals and include the Dampier Archipelago, Bonaparte Archipelago and Ningaloo Reef (Collins et al., 2003).

A detailed account of the geomorphology for the inner shelf, middle shelf, outer shelf and continental slope, and abyssal plain/deep ocean floor is described in the synthesis of literature that follows.

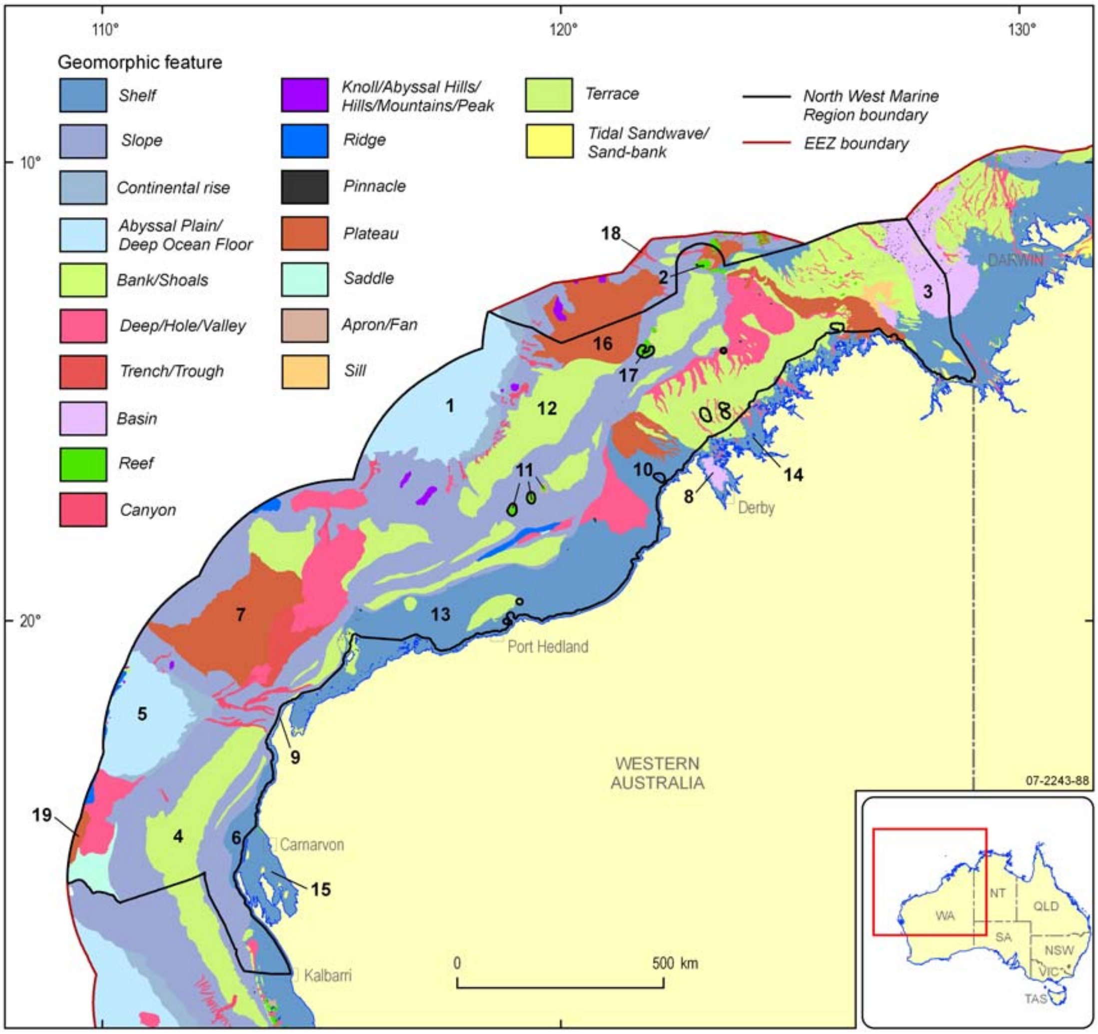

Figure 3.5. The geomorphic features of the NWMR as identified by Heap and Harris (in press). Numbers 1 to 19 refer to key place names which are provided in Table 3.1.

Table 3.1. Place names and associated references for geomorphic features displayed in Figure 3.1.

No.	Geomorphic Feature	Feature Type	References
1	Argo Abyssal Plain	Abyssal Plain (1)	Buffler (1994); Falvey & Veevers (1974)
2	Ashmore Reef	Reef (2)	van Andel & Veevers (1967); Glenn & Collins (2005)
3	Bonaparte Depression	Valley (3)	Lees (1992); van Andel & Veevers (1967)
4	Carnarvon Terrace	Terrace (4)	Symonds & Cameron (1977)
5	Cuvier Abyssal Plain	Abyssal Plain (5)	Colwell et al., (1994)
6	Dirk Hartog Shelf	Shelf (6)	Dix (1989); Dix et al., (2005)
7	Exmouth Plateau	Plateau (7)	Colwell & von Stackelberg (1981); Stagg (1978)
8	King Sound	Basin (8)	Carrigy & Fairbridge (1954)
9	Ningaloo Reef	Reef (9)	Collins et al., (2003)
10	Northwest Shelf	Shelf (10)	Jones (1967; 1970; 1973)

11	Rowley Shoals	Reef (11)	Carrigy & Fairbridge (1954); Jones (1973)
12	Rowley Terrace	Terrace (12)	Falvey & Veevers (1974); Stagg (1978)
13	Rowley Shelf	Shelf (13)	Carrigy & Fairbridge (1954)
14	Sahul Shelf	Shelf (14)	Carrigy & Fairbridge (1954)
15	Shark Bay	Shelf (15)	Woo et al., (2006)
16	Scott Plateau	Plateau (16)	Falvey & Veevers (1974); Stagg (1978)
17	Scott Reef	Reef (17)	Jones (1973)
18	Timor Trough	Trench/Trough (18)	Veevers et al., (1978)
19	Wallaby Plateau	Plateau (19)	Falvey & Veevers 91974); Sayers et al., (2002)

3.1.5.1. Inner Shelf

The inner shelf occurs in water depths of <30 m and covers an area of ~140,000 km^2 (Fig.3.1). It includes prominent areas such as Shark Bay, Ningaloo Reef, and King Sound Basin. Of the three shelf divisions of the NWMR, the Dirk Hartog Shelf occurs mostly in the inner shelf region. The Dirk Hartog Shelf is narrow (~7 km at Ningaloo Reef) with shallow water depths (0-100 m) that concentrate and intensify the LC.

Tidal sand waves/sandbanks are present in the innermost reaches of the Exmouth Gulf and at the entrance to and within the vicinity of Shark Bay. Sand waves combined with seagrass banks in Shark Bay reduce water circulation in the bay and dramatically increase its salinity (Harris et al., 1991). As a result the bay is hyper-saline, and its outflow increases the salinity of the LC (Woo et al., 2006).

Ningaloo Reef is situated off North West Cape and extends for 260 km while maintaining a distance of 1-6 km from the shoreline (Harris et al., 2003). The reef represents the world's largest fringing coral reef and is composed of Holocene reef growth recolonised on an antecedent (Pleistocene) reef basement (Collins et al., 2003). Holocene reef growth occurs predominantly in water depths <30 m and is dominated by robust coral due to the year round exposure to a relatively high wave climate (Collins et al., 2003).

To the south of the Sahul Shelf lies King Sound. The embayment occupies an area of 2,500 km^2 and contains extensive mud flats that are extensively inhabited by mangrove growth (Carrigy and Fairbridge, 1954). The embayment experiences some of the largest tides on the shelf at ~9.2 m (Semeniuk, 1980).

3.1.5.2. Middle Shelf

The middle shelf covers an area of 530,000 km^2 with water depths that range from 30 – 200 m (Fig. 3.1). The middle shelf environment covers the majority of shelf within the NWMR. Prominent geomorphic features of the region include terraces, deeps/holes/valleys, ridges, plateaus and pinnacles. The middle shelf includes the Dirk Hartog, Rowley/Northwest and Sahul Shelves. Available data indicates that the seabed of the Rowley/Northwest Shelf is gentle and smooth while the Sahul Shelf has a complex topography. The Sahul Shelf consists of a series of rises, depressions, banks, terraces and channels (van Andel and Veevers, 1967). Terraces and plateaus are located on the middle shelf and are considerably smaller in size than the larger terraces and plateaus located on the outer shelf/slope.

The Bonaparte Depression is a broad depression located on the middle Sahul Shelf and is bound by the Londonderry and Sahul Rises. The depression comprises a 45,000 km^2 basin that forms an epicontinental sea with a maximum water depth of 155 m (Lees, 1992). The eastern flank of the depression is steep, the western flank very gentle and the south merges into a broad, featureless plain (van Andel and Veevers, 1967). The floor of the depression is relatively flat and punctured by numerous pinnacles and subaqueous banks (Harris et al., 2003). The depression is bounded by the Londonderry, Sahul and Van Diemen Rises (Fig. 3.16). The Matila Shelf Valley is a long, narrow, curved channel that connects the Bonaparte Depression with the Timor Trough and is fringed with small, steep, carbonate banks (van Andel and Veevers, 1967).

Other prominent geomorphic features that occur on the middle shelf include small terraces, deeps/holes/valleys, and trench/troughs. Small terraces parallel to the coast are located on the Rowley Shelf. A larger terrace is situated on the Sahul Shelf and is dissected by a series of deep valleys with a N-W orientation (Harris et al., 2003).

3.1.5.3. Outer Shelf and Slope

The outer shelf and slope extend from ~200 m water depth to the abyssal plain/deep ocean floor at ~4000 m water depth (Fig. 3.1). No distinct shelf break is recognised; rather there is a smooth transition from the outer shelf to the upper slope. The outer shelf/slope is an extensive area of the NWMR and covers 930,000 km^2. Prominent geomorphic features of the outer shelf/slope are the Exmouth Plateau, Scott Plateau, Rowley Terrace, Carnarvon Terrace, areas of knoll/abyssal hills/hill/mountains/peak, and a series of carbonate reefs and algal deposits.

Two large terraces are located on the outer shelf/slope region of the NWMR. These terraces are larger than the terraces located on the middle shelf, run parallel to the coast and include the prominent Carnarvon and Rowley Terraces (Fig. 3.6). The Carnarvon Terrace extends for 800 km to the south of North West Cape, covering an area of 80,000 km^2 of which 60,000 km^2 is within the NWMR. The terrace is located to the east of the Wallaby Plateau and forms a shallow zone on the upper slope (Harris et al., 2003). The Rowley Terrace is located on the slope of the Rowley Shelf and occupies an area of 42,000 km^2.

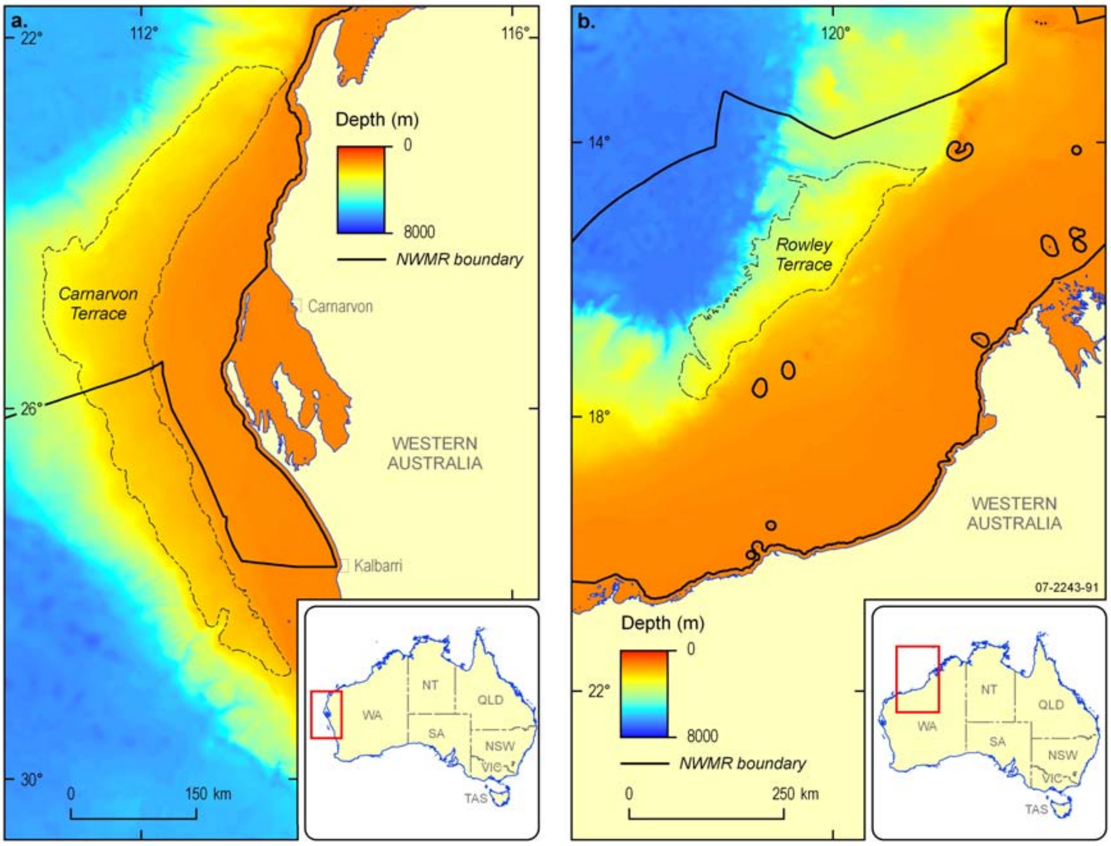

Figure 3.6. Bathymetry of, a) Carnarvon Terrace; b) Rowley Terrace.

Three plateaus are situated on the outer shelf/slope region of the NWMR (Exmouth; Wallaby; and Scott) (Fig. 3.7). The Exmouth Plateau is the smallest, covering an area of ~5,000 km^2, while the Wallaby and Scott Plateaus occupy an area of 70,000 km^2 (Sayers et al., 2002) and 80,000 km^2, respectively. Approximately 2,500 km^2 of the Wallaby and 42,000 km^2 of the Scott Plateau lie in the NWMR. The Wallaby Plateau is bounded to the south by the NW-trending Wallaby-Perth Scarp (the Wallaby-Zenith Fracture Zone) (Harris et al., 2003).

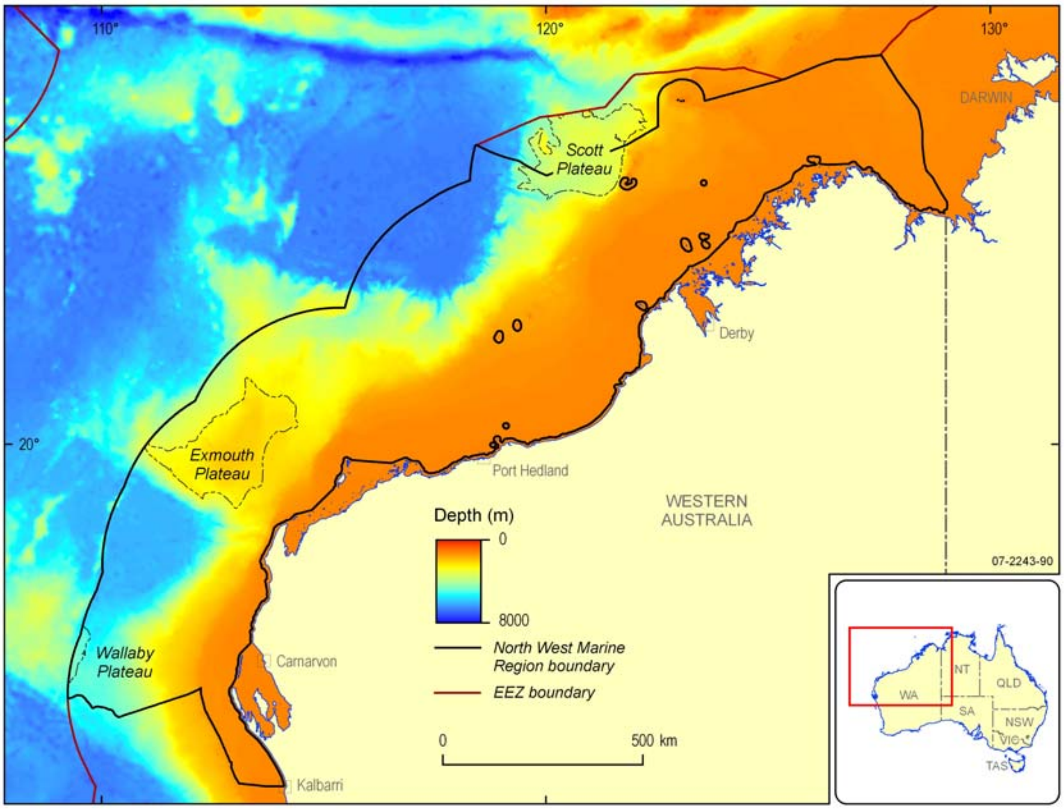

Figure 3.7. Bathymetry and location of the Wallaby, Exmouth and Scott Plateaus.

Carbonate reefs are located along the outer shelf, and their presence indicates subsidence of the shelf edge (Teichert and Fairbridge, 1948). These include the Ashmore, Adele, Browse, Cartier, Seringapatam and Scott Reefs and the Rowley Shoals (Fig. 3.8). Present day coral reefs north of the Ashmore Reef are mostly composed of coralline algae such as *Halimeda*, while south of and including Ashmore Reef they are principally composed of scleractinian corals (Harris et al., 2003). A series of drowned carbonate banks are located at the edge of the Sahul Shelf. These banks are generally 10 km^2 in area with flat tops (developed as terraces and benches), and contain steep slopes of ~20° (van Andel and Veevers, 1967).

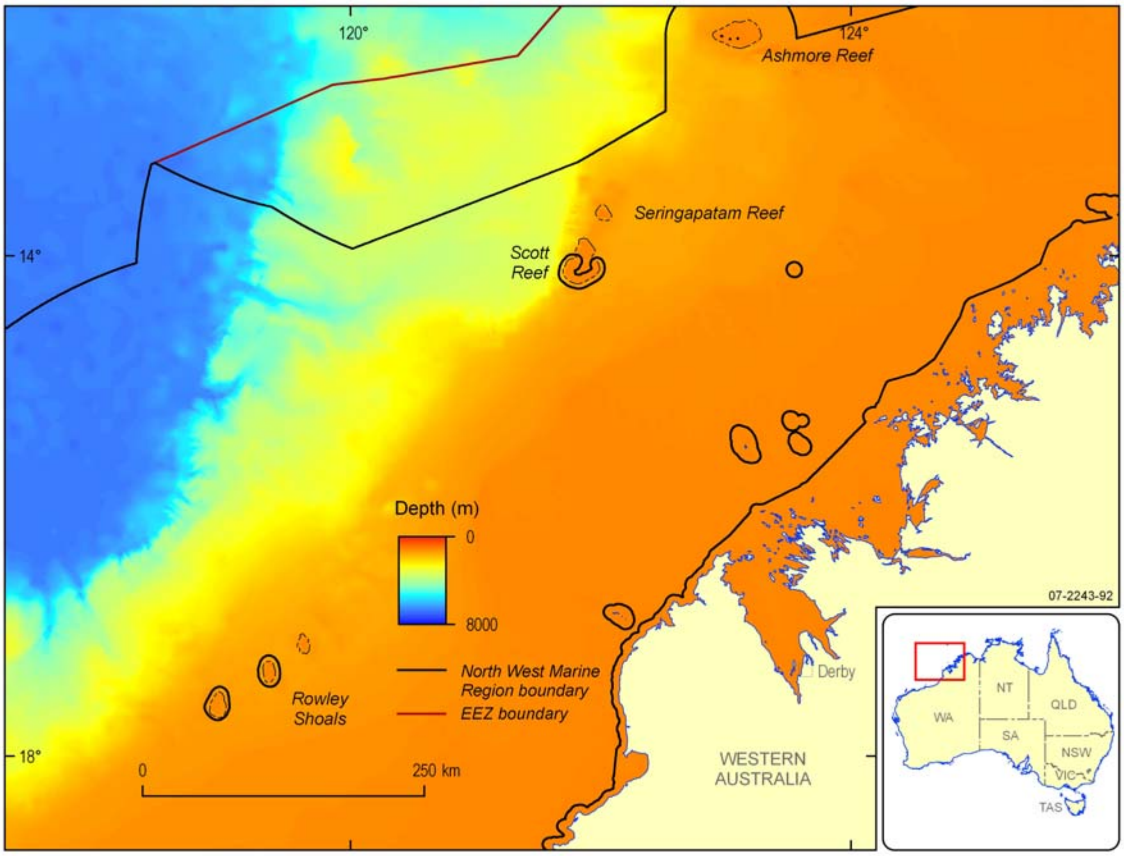

Figure 3.8. Bathymetry and location of the Rowley Shoals, Scott, Seringapatam, and Ashmore Reefs.

The Rowley Shoals are a chain of coral reefs with similar dimensions, shape and orientation and are situated on the slope to the west of the Rowley Shelf (Harris et al., 2003). The shoals are N-S orientated and rise vertically from 440 m water depth (Jones, 1973). The reefs consist of a thick, coral-rich Holocene stratum overlying a Pleistocene (and probably older) reef basement and are located within the headwaters of the southward flowing Leeuwin Current (Hatcher, 1991). Scott Reef is located on the slope to the east of the Scott Plateau and occupies an area of 800 km^2. Scott Reef rises from a depth of ~450 m (Jones, 1973) and consists of two separate atolls (North Reef and South Reef) that are divided by a channel of ~400 m water depth. Ashmore Reef is situated on the slope adjacent to the Sahul Shelf and occupies an area of 720 km^2. The reef is composed of sub-aerial islands that cover an area of 0.55 km^2. The reef is ovoid in shape and lies in water depths <300 m. The southern margin of Ashmore Reef is more robustly developed than the northern margin due to its exposure to an energetic southeast wind and swell regime (Glenn and Collins, 2005).

3.1.5.4. Abyssal Plain/Deep Ocean Floor

The abyssal plain/deep ocean floor of the NWMR lies in water depths of 4,000-6,000 m. The abyssal plain/deep ocean floor is separated into the Cuvier and Argo Abyssal Plains located to the west of the Dirk Hartog Shelf and to the north of the Rowley Shelf, respectively (Fig. 3.9). A total area of 40,000 km^2 of the Cuvier Abyssal Plain and 60,000 km^2 of the Argo Abyssal Plain are located in the NWMR.

The Argo Abyssal Plain lies in water depths of >5,000 m and forms an area of low relief (Harris et al., 2003). The plain is bounded predominantly by slope with a small portion (11,500 km^2 in the NWMR) of rise to the east. Rise also occurs south of the Exmouth Plateau and forms a smooth sediment apron, while northwest of the Exmouth Plateau the surface is rough and undulating (Harris et al., 2003). The surface of the abyssal plain slopes gently to the north and forms the outer ridge to the Java Trench (Buffler, 1994; Falvey and Veevers, 1974). Swales are present in the southwest regions of the plain, and small hills have been identified on the western margin (Harris et al., 2003).

The Cuvier Abyssal Plain is also situated in water depths >5,000 m. The plain is bounded by the Wallaby Plateau to the southwest and the rise to the east. The Cuvier Abyssal Plain deepens to the northwest and forms a possible subaqueous drainage system into the Wharton Basin at 20°S and 108.5°E (Harris et al., 2003). Two prominent ridges trend from the north to northeast from the Wallaby Plateau into the Cuvier Abyssal Plain (Colwell et al., 1994b)

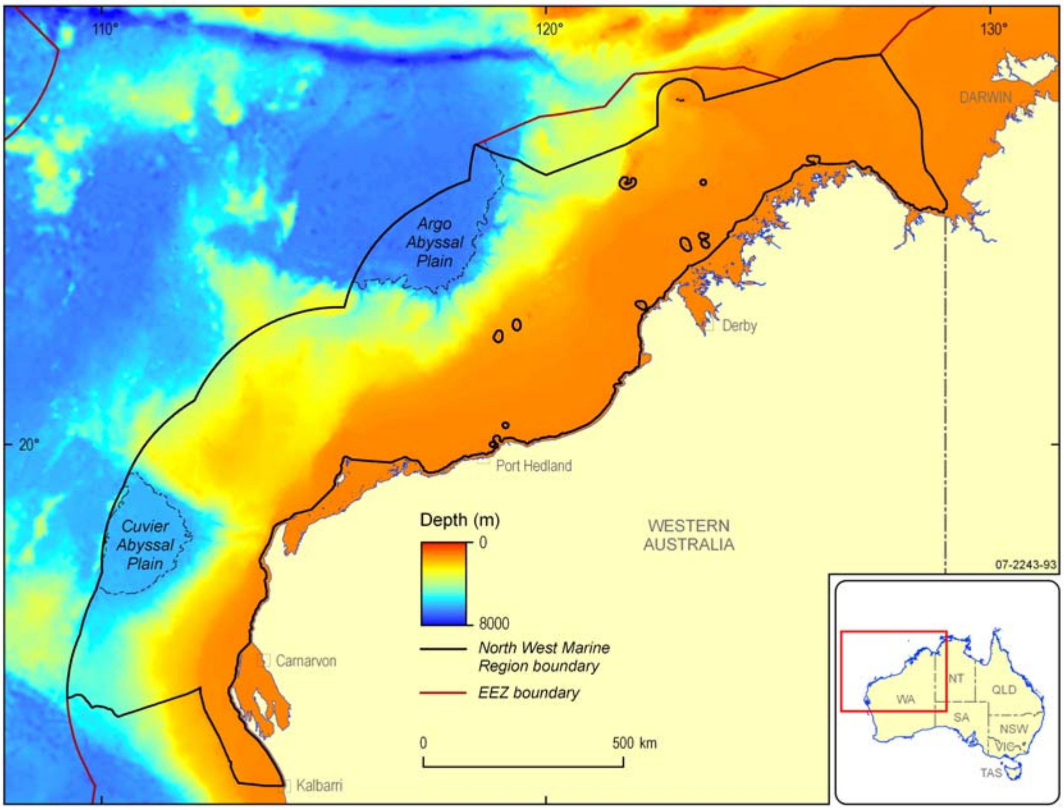

Figure 3.9. Location and bathymetry of the Cuvier and Argo Abyssal Plains.

3.1.6. Sedimentology

Seabed sediments of the NWMR comprise bio-clastic, calcareous and organogenic sediments that were deposited by relatively slow and uniform sedimentation rates (Carrigy and Fairbridge, 1954) (Fig. 3.10). The region is a zone of sediment bypass and winnowing rather than one of active deposition (Jones, 1971). Sediments grade from sands and gravels on the shelf to muds on the slope and abyssal plain/deep ocean floor (Colwell and Von Stackelberg, 1981).

Calcium carbonate deposits are located on the inner shelf, middle shelf and outer shelf/slope. Terrigenous sediments constitute a minor component and occur most frequently within areas of the inner shelf adjacent to rivers.

A variety of processes control the sediment transport mechanisms of the inner shelf, middle shelf, outer shelf/slope and abyssal plain/deep ocean floor. The inner shelf is influenced by the outflow of terrigenous sediments from rivers. Sediments of the middle shelf region are predominantly influenced by tidal processes, including internal tides. Sediments of the outer shelf/slope are influenced through a combination of slope processes and large ocean currents. These processes and their impact on seabed sediments in NWMR are described below (Section 3.1.6.1-3.1.6.2).

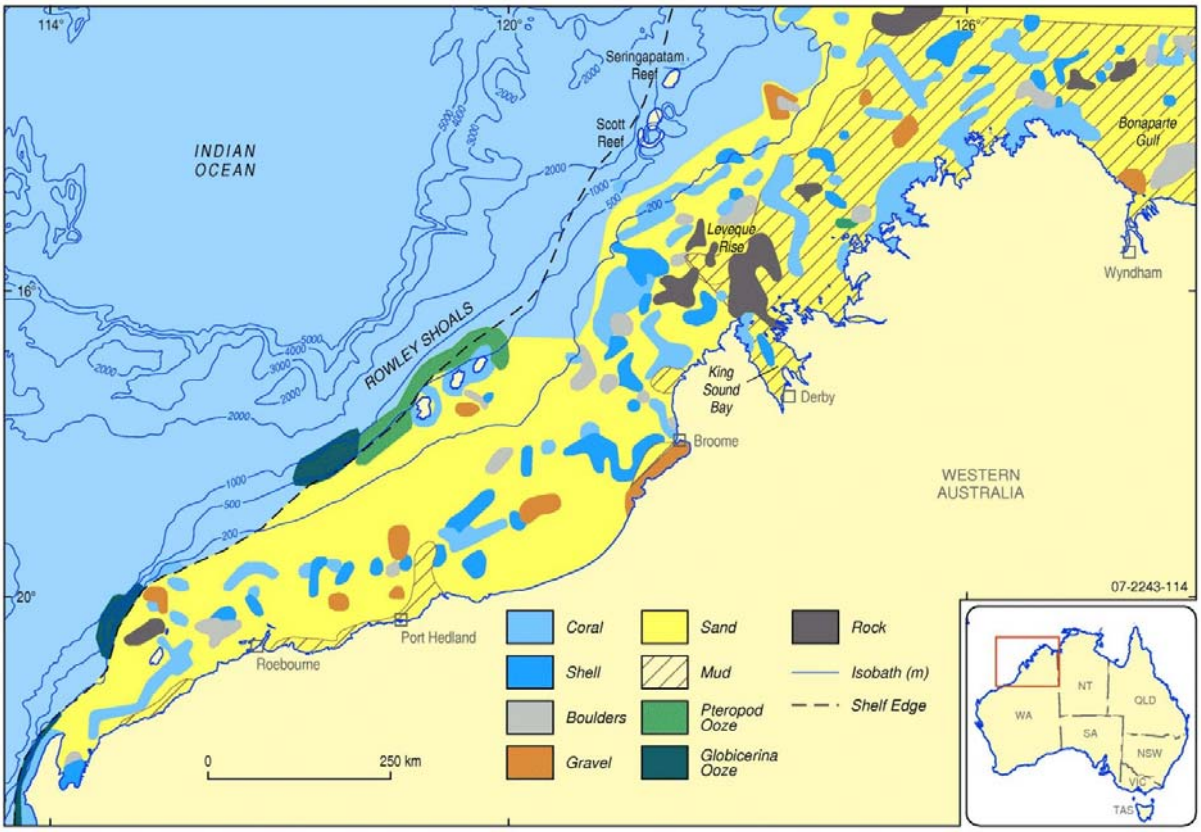

Figure 3.10. Sedimentary facies model of the northwest shelf (Carrigy and Fairbridge, 1954).

3.1.6.1. Inner Shelf

The sedimentology of the inner shelf is characterised by sand, with localised accumulations of mud and gravel. These localised deposits occur at Roeburne, Broome and to the north of the Leveque Rise (Carrigy and Fairbridge, 1954) (Fig 3.10). Sediments of southern inner shelf are mostly carbonates comprising skeletal fragments and lithoclasts (Dix, 1989). Coral fragments are most common southwest of Dampier where fringing reefs have formed a veneer on the Pleistocene basement (Dix et al., 2005). Silt-sized sediments of the Northwest Shelf contain 30% carbonate and 70% siliclastic (non-carbonate) sediments with benthic skeletal fragments that include bivalves, gastropods, sponge spicules, foraminifera and bryozoans (Dix et al., 2005). Planktonic foraminifera occur extensively along the inner shelf and reflect the absence of an oceanic barrier along the shelf (Dix et al., 2005). *Halimeda* grows on hard substrates in the Dirk

Hartog Shelf however but is absent in unconsolidated sediment of the Dirk Hartog Shelf (James et al., 1999) (Fig. 3.11.).

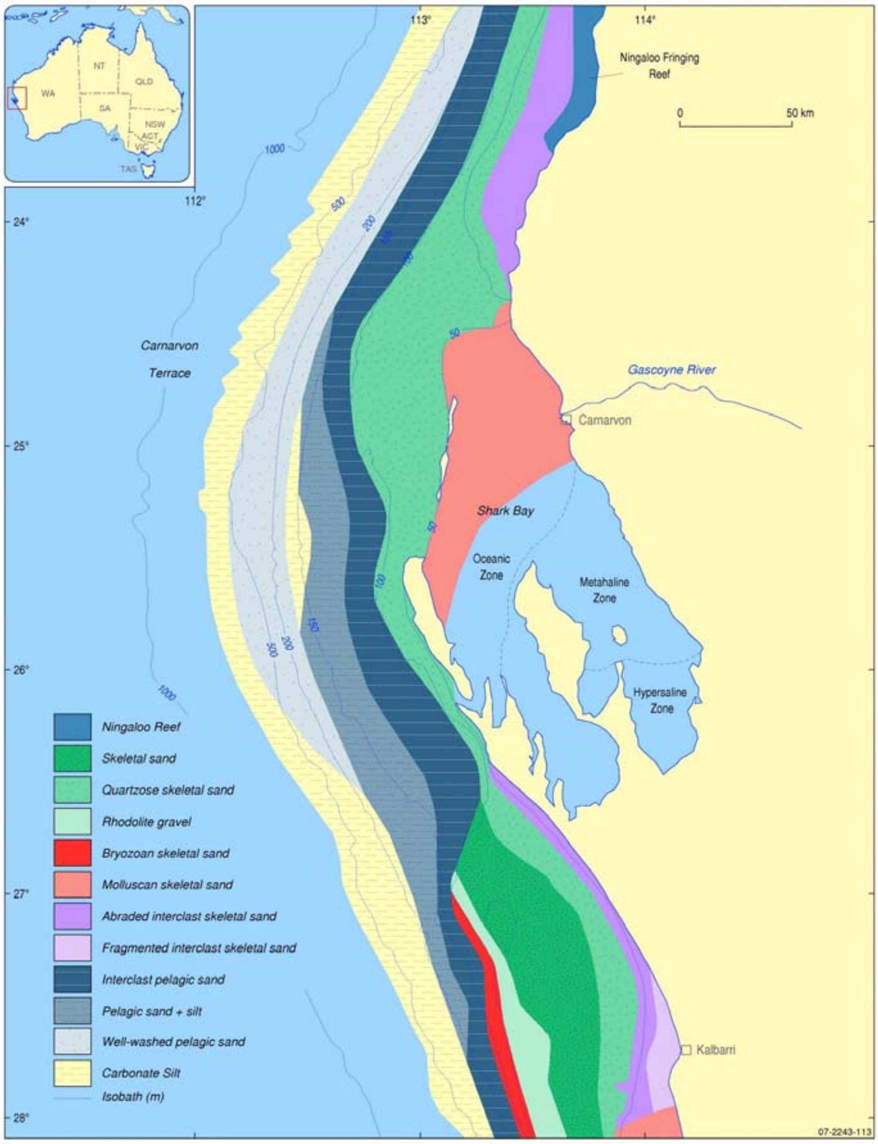

Figure 3.11. Sedimentary facies model of the Dirk Hartog Shelf (James et al., 1999).

Terrigenous sedimentation of the inner shelf is generally low and varies depending on its proximity to rivers. The Sahul Shelf receives most of the terrigenous input of the inner shelf zone, and consequently, terrigenous sediments constitute a moderate component of the seabed sediment (Carrigy and Fairbridge, 1954). The absence of rivers adjacent to the Rowley Shelf has resulted in negligible accumulations of terrigenous sediments on the seabed. The terrigenous component of sediments on the inner Dirk Hartog Shelf contain 30-60% terrigenous grains due to its close proximity to the Gascoyne River (James et al., 1999). These sediments are generally limited to and trapped in estuaries and embayments (Carrigy and Fairbridge, 1954).

Deposition of seabed sediments on the inner shelf is controlled by tidal currents; inner shelf currents, generated by the interaction of water with the underlying rocks and reefs; cyclones; and sediment reworking through winds, tides and waves (Dix, 1989). These interactions have resulted in the deposition of coarse grained (<3 wt % mud) sediments and sand bodies of up to

50 m thickness on the Northwest Shelf (Dix, 1989). The inner Sahul Shelf sediments are gravel and sand dominated, and the area is a zone of sediment bypass where high tidal velocities result in deep erosion (Lees, 1992). Sediment transport and deposition is influenced by the coastal turbidity zone which results in the trapping and suspension of fine terrigenous sediments in close proximity to the coast.

3.1.6.2. Middle Shelf

Seabed sediments of the middle shelf are dominated by sand with accumulations of coral and gravel deposits (Carrigy and Fairbridge, 1954) (Fig. 3.12). Sand dominates the middle shelf and comprises skeletal fragments with a high proportion of relict grains (>30%). These relict grains are most prominent on the Northwest Shelf where sediments are a variable mixture of relict, stranded and Holocene grains (James et al., 2004). A high concentration of mud with localised bands of sand and gravel occur along the Sahul Shelf (Carrigy and Fairbridge, 1954). Shallower (~ 70 m water depth) parts of the Dirk Hartog Shelf are covered with medium to coarse grained sands while deeper areas (~70-100 m water depth) contain poorly sorted sediments (James et al., 1999). Prior to the present study, the seabed sediments of the region were known to be relatively coarse and sand dominated, with ~90% calcium carbonate content and relict material distributed throughout (Jones, 1970; Jones, 1973).

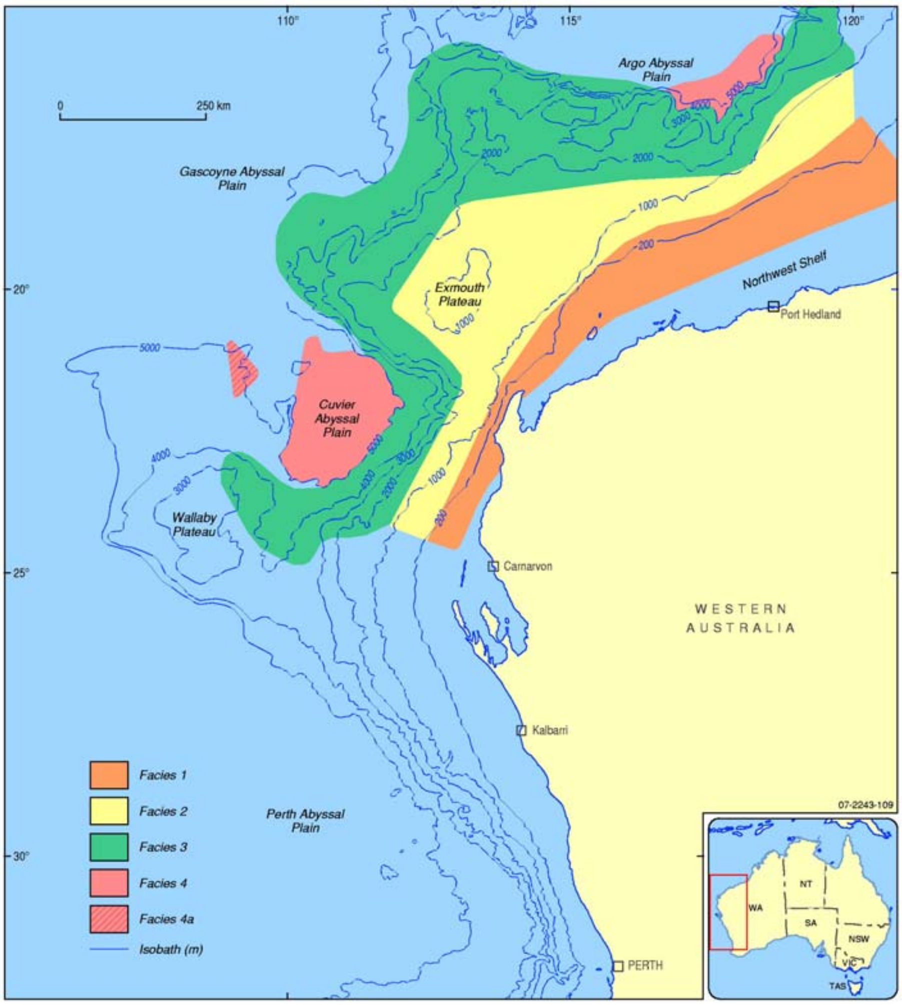

Figure 3.12. Sediment facies of the northwest margin, facies 1) shell fragments, pteropods, benthic and planktonic foraminifera; facies 2) pteropods, planktonic foraminifera; 3) planktonic foraminifera; facies 4) radiolarian, diatoms, partly dissolved planktonic foraminifera (Colwell and Von Stackelberg, 1981).

The Northwest Shelf is characterised by an extensive accumulation of relict Holocene grains that were stranded during the marine transgression (Dix et al., 2005). This Holocene sedimentary deposit has been extensively documented by James et al (2004) and consists of relict intraclasts, both skeletal and lithic, that formed during sea-level highstands of Marine Isotope Stages 3 and 4. The most notable of these sediments are ooids and peloids that formed 15.4-12.7 ka BP (James et al., 2004) (Fig. 3.13). Seasonal evaporation on the inner shelf creates a seawards movement of bottom water that has limited the present day production of calcium carbonate on the middle shelf (James et al., 2004).

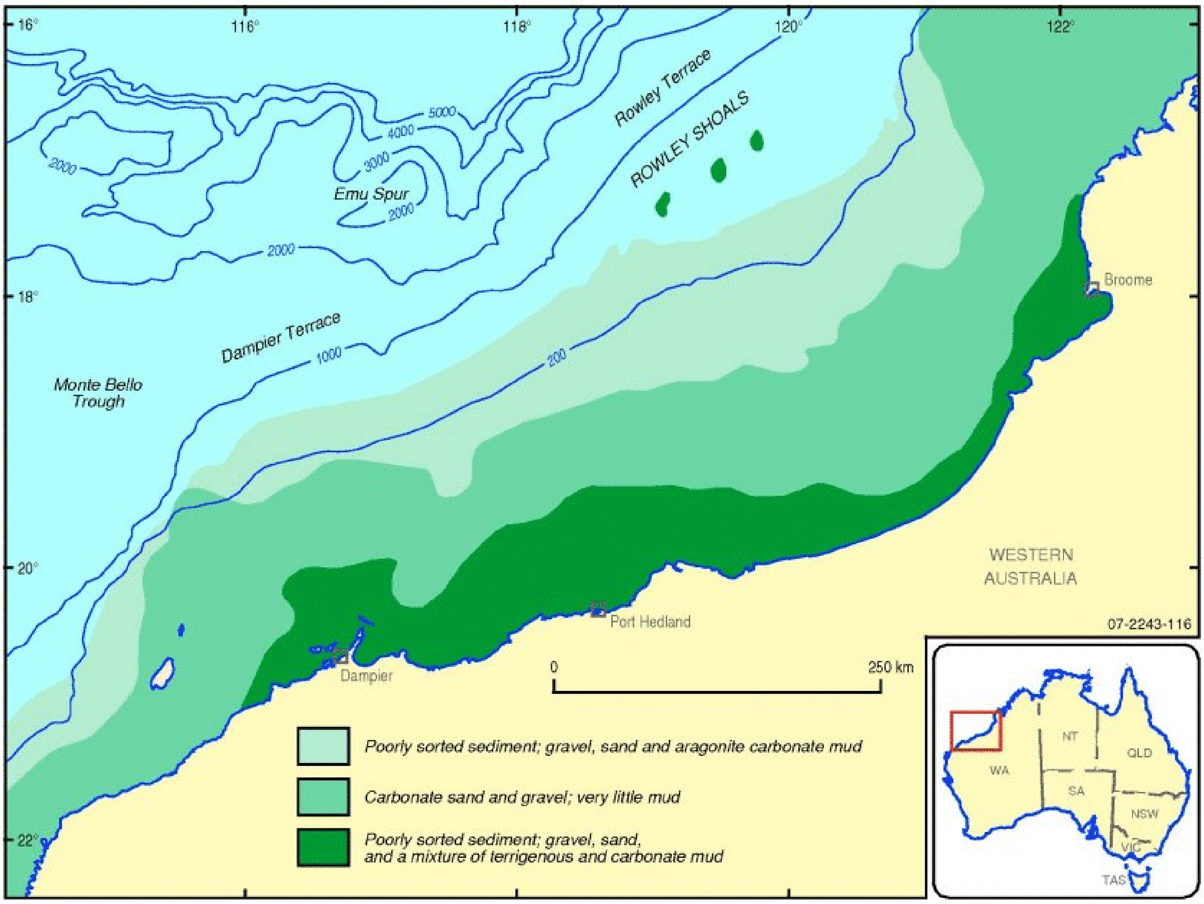

Figure 3.13. Seabed sediments of the Northwest Shelf (James et al., 2004).

Sediment transport on the middle shelf is influenced by a combination of processes from the inner and outer shelf including winds, tides and waves, coastal turbidity, and slope processes. Sediments are reworked through a combination of tidal and wave currents (Dix et al., 2005) and well-polished through continual wave abrasion (James et al., 1999).

3.1.6.3. Outer Shelf and Slope

The outer shelf and slope is dominated by fine grained sediments (Jones, 1973) with thicker accumulations of carbonate deposits at the shelf edge. Carbonate mud constitutes a major component of the sediment and contains modern pelagic ooze and aragonitic needle-rich micrite (Dix et al., 2005). An extensive series of carbonate reefs located on the outer shelf are surrounded by deposits of coarse and fine coraligenous clastics (Carrigy and Fairbridge, 1954). The sand fraction of sediments of the outer shelf consists mainly of planktonic foraminifera and is bounded by a belt of rapidly deposited silt-sized carbonate and terrigenous sediment (Jones, 1973). Further seawards, on the slope, slower rates of sedimentation occur and result in an increase in the proportion of sand-sized planktonic foraminifera (Jones, 1973). Small pellets (0.1 mm in diameter) are located on slope of the Northwest Shelf and these are either faecal in origin or are turbid micrite clasts of small planktonic foraminifera (Jones, 1973).

Sediment from the Exmouth Plateau consists mainly of foraminiferal ooze and sand composed of 20-60% sand and 60-75% calcium carbonate grains (Colwell and Von Stackelberg, 1981). The fine fraction of the surficial sediment consists of planktonic foraminifera (Colwell and Von Stackelberg, 1981). Benthic mollusc fragments, pteropod shells, and planktonic and benthic foraminifera constitute the major skeletal component (Colwell and Von Stackelberg, 1981). The sedimentology varies in composition with water depth and reflects the abundance of biogenic components. As water depth increases, the sediment grades from calcareous oozes and sands to siliceous clays (Colwell and Von Stackelberg, 1981). The high proportion of sand in the sediments suggests winnowing of finer material by bottom currents (Colwell and Von Stackelberg, 1981). The distribution of clay minerals in contours suggests the outer slope is affected by the Western Australia (WAC) and Eastern Gyral Currents (EGC) (Figure 3.2) (Gingele et al., 2001a).

Seabed sediments of the Timor Trough are predominantly composed of silty clays separated from the Sahul Shelf by a narrow band of sandy-silty clay at the top of the continental slope (van Andel and Veevers, 1967). Calcarenite clays occur in deep water regions and contain planktonic foraminifera (van Andel and Veevers, 1967). The carbonate content of sediments ranges from 15-100%, is dependent on grain size, and varies along a gradient from ~75-100% carbonate content on the outer shelf to ~0-50% comprising calcareous clays near the island of Timor (van Andel and Veevers, 1967).

The texture and composition of sediments of the outer shelf and slope are influenced by bottom currents, oceanic upwelling, and large scale currents such as the WAC, EGC and LC.

3.1.6.4. Abyssal Plain/Deep Ocean Floor

Seabed sediments of the abyssal plain/deep ocean floor are dominated by fine grained sediment. Due to the difficulty obtaining sediments from the area, knowledge of seabed sediments is limited in comparison to that of the shelf and slope. The Deep Sea Drilling Program (Deep Sea Drilling Program Initial Report; 27) has collected two cores from abyssal plains offshore Western Australia and the composition of one core from the Argo Abyssal Plain is stored in the MARS database. This sample contains 86% mud and less than 1% calcium carbonate. Veevers et al (1974) analysed this sample and showed that seabed sediments of the Argo Abyssal Plain are composed of a thin section of Cainozoic ooze and clay.

The basement of the Cuvier Abyssal Plain is overlain by a horizontal unit of well-stratified sediments (Deep Sea Drilling Initial Report; 27). The Cuvier Abyssal Plain receives significant amounts of terrigenous sediment sourced from the continent which is then debouched onto the deeper Wharton Basin (Harris et al., 2003). In general, seabed sediments of the deep ocean grade from sands to siliceous clays with increasing water depth (Colwell and Von Stackelberg, 1981). The calcium carbonate content of sediments on the abyssal plain/deep ocean floor is negligible because the area lies below the carbonate compensation depth of 4,500-5,000 m (Colwell and Von Stackelberg, 1981).

3.2. THE NOMINATED AREA OF THE NORTHERN MARINE REGION

3.2.1. Introduction

The nominated area of the Northern Marine Region (NNMR) extends from the Bonaparte Gulf in the west to Aurari Bay in the east. The region covers an area of 161,000 km^2 and is contained within the larger Northern Marine Region (NMR). The tectonic history, oceanography, Late Quaternary evolution, geomorphology and surficial sedimentology of the NNMR have been the focus of extensive research. Geomorphic features of the NNMR have been mapped using a consistent bathymetric grid of Australia's EEZ and relevant scientific literature (Heap and Harris, in press). A summary of the key geological and oceanographic events as well as prominent sedimentary and geomorphic features within the NNMR are provided below.

3.2.2. Tectonic History

The NNMR is an active continental margin with a complex tectonic history that is reflected in the geomorphology and geology of the region. The NNMR is a submerged section of the Australian continental crust which is bound to the north by an extinct accreting plate margin (Jongsma, 1974; Nicol, 1970). Tectonic rises and depressions located in the NNMR, such as the Van Diemen Rise, are attributed to the collision of the Australian platform with Papua New Guinea and Indonesia (Jongsma, 1974). Major geological provinces within the NNMR include the Arafura Basin and Goulburn Graben. The Arafura Basin is filled with Cambrian to Permo-Triassic (~542 – 251 Ma) sediment that is overlain by the middle Jurassic (~175 Ma) sediments of the Money Shoal Basin (Bradshaw et al., 1990). The Arafura Basin consists of northern and southern platforms that are separated by a northwest inclining Goulburn Graben situated on the southern margin (Heap et al., 2004; Moore, 1995) (Fig. 3.15). The Goulburn Graben is filled with marine clastics and carbonates which vary in age from the lower Cambrian to the Permian (~542 – 299 Ma) (Moore, 1995).

The major tectonic events of the NNMR summarised in chronological order are as follows:

- Permian-Triassic (~251 Ma) boundary – Continental break-up of northern Gondwana occurred (Pigram and Panggabean, 1981). This is recorded in a rift-drift sequence that extends along the northern margin of Australia (Brown, 1980; Pigram and Panggabean, 1981; Pigram and Panggabean, 1984).
- Middle Jurassic (~175 Ma) – A period of seafloor spreading and crustal uplift of northern Australia occurred (Audley-Charles et al., 1988; Pigram and Panggabean, 1984).
- Late Jurassic (~165 – 161 Ma) – The northern margin of Australia faced a seaway that linked the Indian and Pacific Oceans (Pigram and Panggabean, 1984).
- Cretaceous to Palaeogene (~145.5 – 23 Ma) – A period of profound subsidence occurred that exposed the islands of the Outer Band Arc (Audley-Charles et al., 1988).
- Cainozoic (~65.6 Ma – present) – Tectonic collision occurred, resulting in major strike and slip movements that are reflected in the bed forms of the northern margin (Audley-Charles et al., 1988).

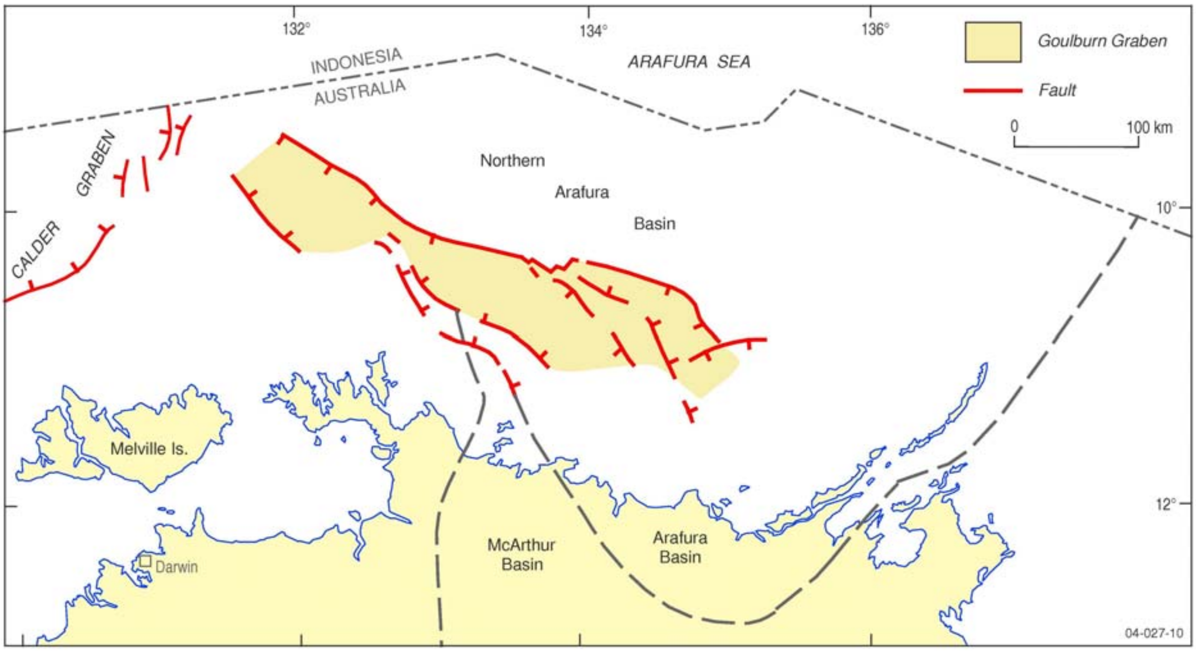

Figure 3.14. The geological setting of the Arafura Shelf, including the Arafura Basin and Goulburn Graben (from Moore, 1995).

3.2.3. Oceanography

The NNMR is a high energy oceanographic environment dominated by macro-tides, tropical cyclones and seasonal reversals of ocean currents. Tidal regimes follow semidiurnal and diurnal patterns, and generally attain more than 4 m. The tidal range is between 5.5 m - 7.9 m at Darwin and from 2 m - 4 m east of Darwin (Harris, 1994; Harris et al., 1991; Porter-Smith et al., 2004). Sea surface temperatures range from 25 - 29°C and average 27°C (Morrison and Delaney, 1996).

Circulation of the NNMR is influenced by the South Equatorial Current (SEC) and the Indonesian Throughflow (ITF) (Harris et al., 1991; Morrison and Delaney, 1996). Seasonal reversals of current flow occur in response to seasonal monsoons experienced in the region (Cresswell, 1992; Cresswell et al., 1993; Gupta, 2006). From April to November the SEC causes surface currents to flow westwards at a maximum mean rate of 0.5 ms^{-1} (Australian Pilot Volume V, 1992). This causes upwelling on the outer shelf and slope and increases productivity (Rochford, 1966). During the monsoonal season from December to March, current flow is weaker and unidirectional (Harris et al., 1991).

The oceanography of the NNMR influences the transport and deposition of seabed sediments. Inner shelf sediments are transported offshore by strong tides (Lees, 1992) that resuspend sediment into the water column (Morrison and Delaney, 1996). Outer shelf and slope sediments are transported by tropical cyclones that occur from November to March (Lourensz, 1981; Morrison and Delaney, 1996; Porter-Smith et al., 2004). These cyclones create strong winds and promote water movement that contribute to the erosion and deposition of fine-grained seabed sediments over large distances (Gagan, 1990; Harris, 1995).

3.2.4. Late Quaternary Evolution

The present day morphology of the NNMR is largely a result of low sea level erosional processes that occurred throughout the late Quaternary (Jongsma, 1974). During the LGM at ~18 ka BP, the shoreline of the Arafura and Sahul Shelf was 110 – 130 m below present position; and the shelves, including the Van Diemen Rise, were emergent and covered with arid woodland and dry sclerophyll vegetation (van Andel and Veevers, 1967; van der Kaars, 1991). By 15 ka BP – 13 ka BP, sea level had risen to ~55 m below its present position and mangroves and salt marsh occupied a large area of a low lying coastal plain (Lavering, 1994; van der Kaars, 1991). At about 9 ka BP, sea level rose to 15 m below present and stabilised at ~6 ka BP, bringing the shoreline to within ± 1-2 m of its present position (Lavering, 1994; van Andel and Veevers, 1967; van der Kaars, 1991).

Various geomorphic features, including terraces and palaeochannels, occur within the NNMR that reflect late Quaternary sea level fluctuations and the palaeoenvironment of the region. Several notches, steps, terraces, and scarps line the outer shelf and upper slope of the Arafura and Sahul Shelves. These occur at water depths of 122 m, 134 m, 147 m, 154 m, 163 m, 174 m, 181 m, and 225 m and record erosional processes probably associated with Pleistocene sea level fluctuations (Jongsma, 1974). A relict submarine valley system that acted as a passage for fluvial runoff during periods of low sea level extends from the Arafura Sill to the Arafura Depression within the NNMR (Harris et al., 1991). When sea level stabilised at ~6 ka BP the delivery of terrigenous sediment to the shelf decreased and the palaeochannels of this fluvial system were in-filled with marine dominated material (Grosjean et al., 2007).

Throughout the late Quaternary the NNMR was the site of limited coral reef growth (Napier, 1991). Relict reefs are located on the outer shelf/slope and on the sides of drainage channels, but they are less abundant than those of the NWMR (Harris et al., 1991). Reefs in the NNMR are sparsely distributed and probably grew in areas of local upwelling from the Timor Sea, flourishing through periods of high sea level and subjected to erosion during sea level lowstands (Heap et al., 2004).

3.2.5. Geomorphology

The NNMR comprises a complex geomorphology, which includes prominent features such as the Arafura Depression, Arafura Shelf, Bonaparte Depression, Flinders-Evans Shoals, Malita Shelf Valley, Parry Shoal, Sahul Shelf, and the Van Diemen Rise (Fig. 3.16 & Table 3.2.). Unassigned continental shelf covers the majority of the region, and this is intersected by a series of channels, terraces and ridges. The geomorphology of the NNMR is complex and represented by 12 of the 21 geomorphic features identified within Australia's EEZ (Heap and Harris, in press). These include: shelf (56.45% of total area within the NNMR), slope (3.54%), banks/shoals (5.46%), deeps/holes/valley (3.92%), basin (11.71%), reef (0.28%), canyon (1.13%), ridge (0.12%), pinnacle (0.23%), apron/fan (1.35%), terrace (15.65%), and tidal sand wave/sandbank (0.17%).

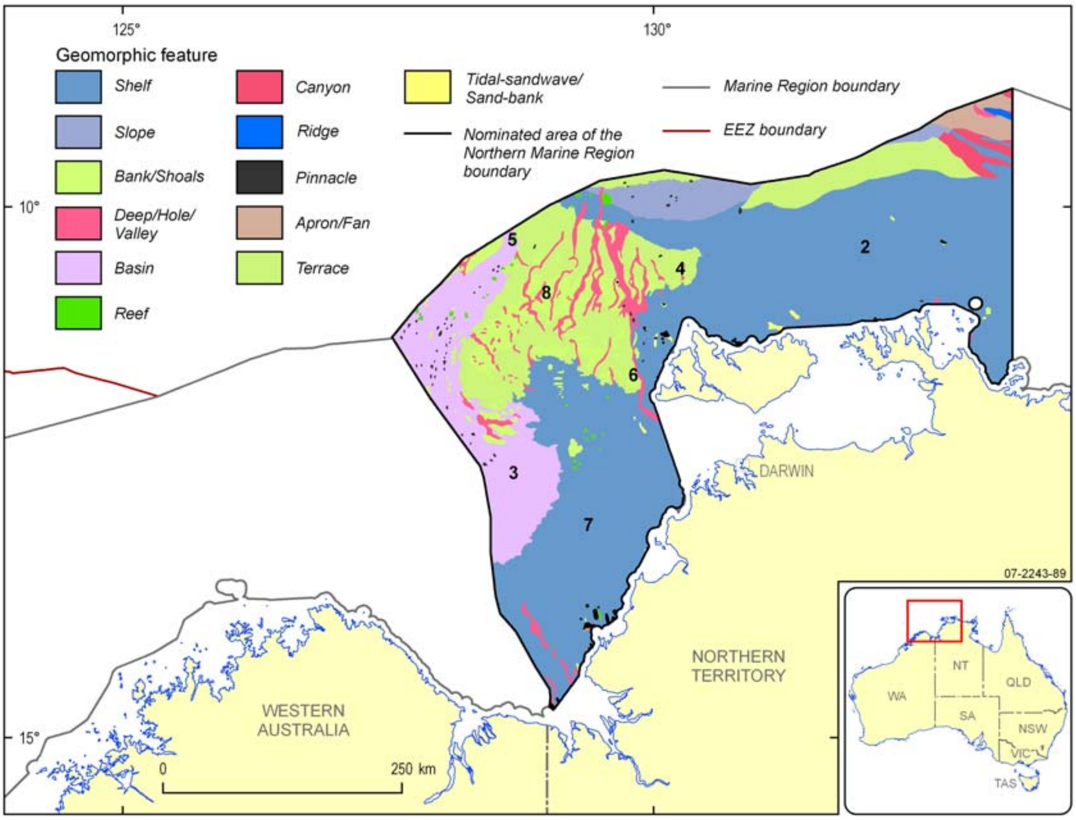

Figure 3.15. The geomorphic features of the NNMR as identified by Heap and Harris (in press). For key place names see Table 3.2.

Table 3.2. Place names and associated references for geomorphic features displayed in Figure 3.2.

No.	Geomorphic Feature	Feature Type	References
1	Arafura Depression	Valley (6)	Jongsma (1974)
2	Arafura Shelf	Shelf (1)	Carrigy & Fairbridge (1954)
3	Bonaparte Depression	Valley (6)	Lees (1992); van Andel & Veevers (1967)
4	Flinders-Evans Shoals	Bank (5)	van Andel & Veevers (1967)
5	Malita Shelf Valley	Valley (6)	van Andel & Veevers (1967); Lees (1992)
6	Parry Shoal	Shoal (5)	van Andel & Veevers (1967)
7	Sahul Shelf	Shelf (1)	Fairbridge (1953); van Andel & Veevers (1967)
8	Van Diemen Rise	Bank (5)	van Andel & Veevers (1967)

Continental shelf within the NNMR is separated into two portions, namely the Sahul and the Arafura Shelf. The Arafura Shelf covers an area of ~630,000 km^2 (Nicol, 1970) and is bound to the west by the Sahul Rise, to the north by the Arafura Depression and to the south by the Wessel Rise. The Sahul Shelf covers a total area of 415,000 km^2 (Carrigy and Fairbridge, 1954) of which 35,410 km^2 lies within the NNMR. The shelf extends from the Sahul Rise in the east to Cape Leveque in the NWMR.

The geomorphology of the Sahul Shelf is complex and consists of a series of rises, depressions, banks, terraces and channels (van Andel and Veevers, 1967). A series of submerged carbonate banks are located along the shelf edge and are separated from one another by narrow sinuous channels of up to 150 km in depth (Harris et al., 2003). Banks are interpreted by Lavering (1994) to be drowned carbonate platforms that were unable to keep pace with rising sea level during the Holocene. The banks are generally <10 km^2 in area with flat tops and developed both as terraces and benches and contain steep slopes of up to 33°, with an average of 20° (van Andel and Veevers, 1967).

The Arafura Shelf is the northernmost extension of Australia's continental shelf and is a broad and gentle seaward sloping plain of up to 350 km in width. Water depths on the Arafura Shelf range from 30 – 190 m, with the shelf edge situated in water depths of 120 – 180 m (Jongsma, 1974). The present day geomorphology of the shelf is largely the result of low sea level erosional processes that occurred throughout the Late Quaternary (Jongsma, 1974) (see section 3.2.4). The central and southern sections of the shelf are flat and mainly featureless except where the shelf approaches the Van Diemen Rise (Jongsma, 1974). The Van Diemen Rise is a complex topographic surface that separates the Arafura and Sahul Shelves. It consists of a series of algal banks that are separated from one another by narrow sinuous channels (Harris et al., 1991; Jongsma, 1974). To the east of the Van Diemen Rise lie the Parry and Flinders-Evans Shoals (van Andel and Veevers, 1967).

Two prominent depressions are located on the Arafura and Sahul Shelves, namely the Arafura and Bonaparte Depression. The Arafura Depression is located on the outer shelf/slope of the Arafura Shelf. A total of 5,000 km^2 of the depression is situated within the NNMR. The depression is a drowned fluvial system, composed of a series of ridges and valleys that existed throughout the LGM (Jongsma, 1974) (see section 3.2.4). A hummocky sedimentary fan occurs in the depression in water depths of 200-300 m, of which only the southernmost section is contained within the NNMR (Jongsma, 1974).

The Bonaparte Depression is a broad depression that occurs on the inner to middle Sahul Shelf that is bounded by the Londonderry, Sahul and Van Diemen Rises. The depression is a 45,000 km^2 basin that forms an epicontinental sea with a maximum water depth of 155 m (Lees, 1992). The eastern flank of the depression is relatively steep, the western flank relatively gentle, and the south merges into a broad featureless plain (van Andel and Veevers, 1967). The floor is relatively flat and punctuated by numerous pinnacles and subaqueous banks (Harris et al., 1991). The Malita Shelf Valley is located to the north of the Bonaparte Depression and connects the depression to the Timor Trough. The valley is a long, narrow, curved channel that is fringed by small, steep, carbonate banks (van Andel and Veevers, 1967).

3.2.6. Sedimentology

Seabed sediments of the Arafura and Sahul Shelves are predominantly composed of coarse-grained calcareous material that is mostly transported by strong tidal currents and seasonal cyclones (Jongsma, 1974; Porter-Smith et al., 2004; van Andel and Veevers, 1967). Terrigenous sediments reach the Sahul Shelf from large river systems that deliver 1.96 ± 106 T of sediment to the Bonaparte Gulf each year (Lees, 1992). Terrigenous sediments on the Arafura Shelf have originated from Arnhem Land rivers, the Gulf of Carpentaria and from reworking of shelf sediments during the last transgression (Grosjean et al., 2007). Sedimentation rates of the

Arafura Shelf since the LGM have remained at 2 m/1,000 years on the inner shelf and 0.1 m/1,000 years on the middle shelf (Jongsma, 1974).

The distribution of seabed sediments in the Joseph Bonaparte Gulf and contained within the Sahul Shelf reflect the present-day oceanographic condition and display a distinct seaward fining pattern (Lees, 1992). Sediments are predominantly carbonate sands with extensive outer shelf foraminiferal facies and algal-foraminiferal banks (van Andel and Veevers, 1967). The transportation and reworking of relict carbonate material masks the significant terrigenous component of sediments delivered to the Gulf, resulting in the deposition of a lobe of mixed carbonate and terrigenous facies that define the path of bed-load transport (Lees, 1992). As tidal velocities decrease with distance offshore the sandy gravel and gravelly sand on the inner shelf grades to sand on the middle shelf and then to silty sands and clayey sands on the outer shelf (Lees, 1992).

Seabed sediments of the Arafura Shelf contain carbonate contents that range from 8 – 100% (Jongsma, 1974) (Fig. 3.16). The carbonate content increases with distance from sources of terrigenous sediments, such as the shelf edge, where coarse sediments have a carbonate content of >50% (Jongsma, 1974). North of Melville and Bathurst Island, a zone of almost pure calcarenite exists comprising abundant foraminifera and mollusc shells (Jongsma, 1974). Lower carbonate contents occur on the middle shelf region due to the input of terrigenous sediment from the mainland (Jongsma, 1974).

The textural component of sediments from the Arafura Shelf is dominated by coarse-grained sands and silty-clays (Jongsma, 1974) (Fig. 3.17). The gravel content of the inner shelf is mostly of terrigenous origin and composed of ferruginous siltstone and sandstone fragments (Jongsma, 1974). Foraminifera, benthic molluscs, bryozoans, echinoids, pteropods, calcareous algae and coral also form constituents of sediments on the Arafura Shelf. Planktonic foraminifera are abundant on the shelf however they are rare or absent in near shore samples (Jongsma, 1974). The coarsest sediments are located on banks and shoals such as the Flinders-Evans Shoal and Parry Shoal (Lavering, 1994). Fine-grained pelagic sediments are located on the upper slope where sediment accumulation has remained un-interrupted during the last two million years (Jongsma, 1974).

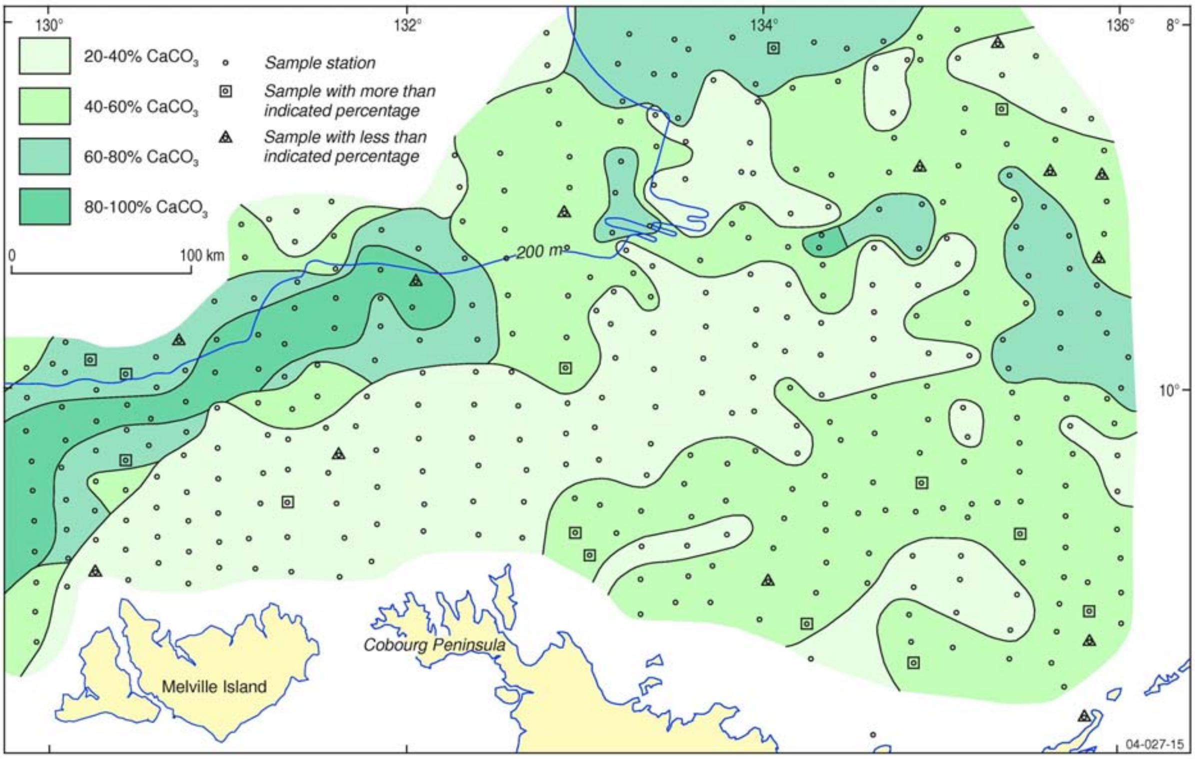

Figure 3.16. The distribution of calcium carbonate concentrations on the Arafura Shelf (redrawn from Jongsma, 1974).

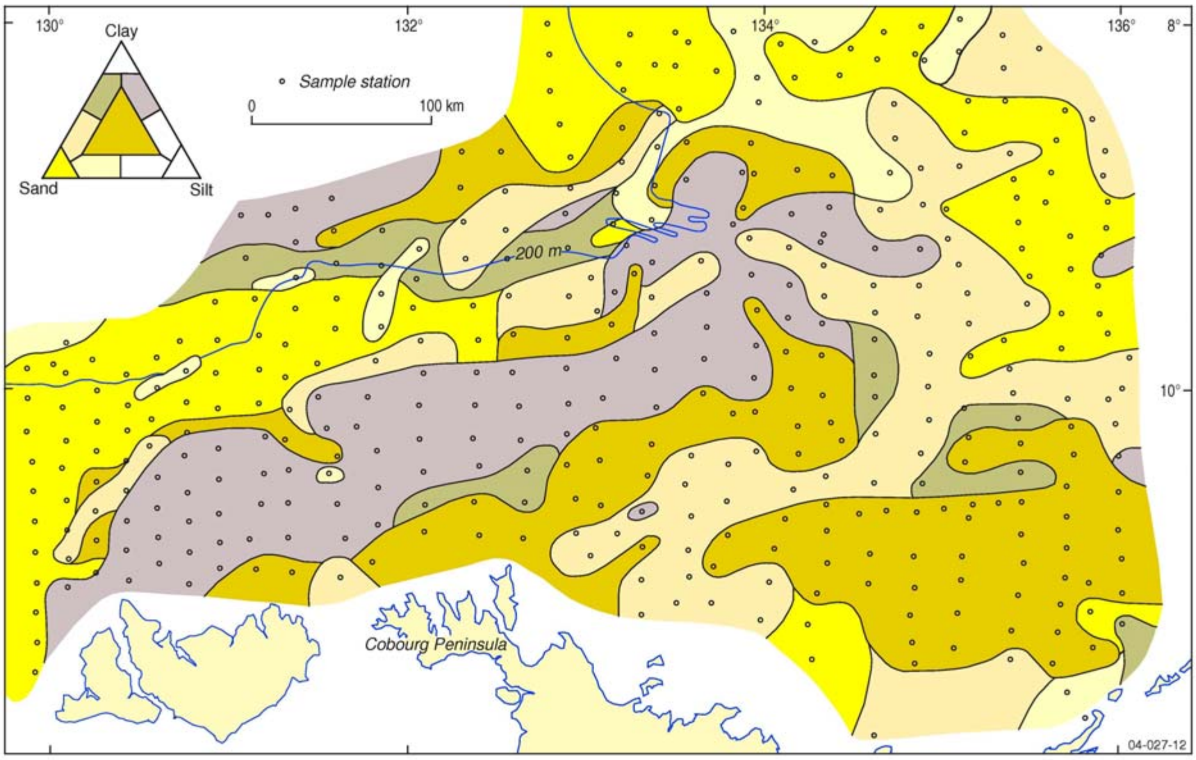

Figure 3.17. The distribution of surface sediments on the Arafura Shelf (redrawn from Jongsma, 1974).