Sedimentology and Geomorphology of the East Marine region of Australia

A Spatial Analysis

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# Table of Contents

LIST OF FIGURES .......................................................................................................................................................... VII  
LIST OF TABLES ........................................................................................................................................................... XV  
ACKNOWLEDGEMENTS ................................................................................................................................................ XVI  
EXECUTIVE SUMMARY ................................................................................................................................................... XVII  

1. INTRODUCTION ........................................................................................................................................................... 1  
1.1. BACKGROUND ......................................................................................................................................................... 1  
1.2. SCOPE ........................................................................................................................................................................ 1  
1.2.1. Generation and Synthesis of Seabed Information for the EMR .............................................................................. 1  
1.2.2. Expected Project Outcomes ....................................................................................................................................... 2  
1.2.3. Products and Outputs ................................................................................................................................................. 2  
1.3. MARINE REGIONS AND BIOREGIONS .......................................................................................................................... 3  
1.3.1. The East Marine Region (EMR) ................................................................................................................................. 3  
1.3.2. EMR Bioregions .............................................................................................................................................................. 3  
1.4. REPORT AIMS AND STRUCTURE ................................................................................................................................ 4  

2. DATA AND METHODS ...................................................................................................................................................... 7  
2.1. EXISTING PHYSICAL DATA FOR THE EMR .................................................................................................................... 7  
2.1.1. Bathymetry .................................................................................................................................................................. 7  
2.1.2. Geomorphology ............................................................................................................................................................. 9  
2.1.3. Sediment Data ............................................................................................................................................................. 9  
2.2. PREVIOUS DATA COVERAGE OF THE EMR ................................................................................................................ 11  
2.3. ASSESSMENT OF SIGNIFICANT GAPS IN EXISTING SAMPLE COVERAGE FOR THE EMR ............................ 12  
2.4. SAMPLE IDENTIFICATION IN THE EMR AND SELECTION FOR ANALYSIS .............................................................. 12  
2.4.1. Sample Identification ................................................................................................................................................... 12  
2.4.2. Sample Selection ......................................................................................................................................................... 13  
2.5. SAMPLE ACQUISITION AND ANALYSIS .................................................................................................................... 16  
2.6. ASSESSMENT OF SIGNIFICANT GEOMORPHIC FEATURES .......................................................................................... 16  
2.7. MAP PRODUCTION ....................................................................................................................................................... 17  
2.7.1. Percent Gravel/Sand/Mud and Folk Classification and Percent Carbonate ................................................................. 17  

3. REVIEW AND SYNTHESIS OF LITERATURE FOR THE EAST MARINE REGION ......................................................... 18  
3.1. INTRODUCTION .............................................................................................................................................................. 18  
3.1.1 Tectonic History ................................................................................................................................................................ 18  
3.1.2 Oceanography ............................................................................................................................................................... 31  
3.1.3 Quaternary Evolution ..................................................................................................................................................... 32  
3.2. SOUTHEAST AUSTRALIAN SHELF .................................................................................................................................... 34  
3.2.1. Geomorphology ............................................................................................................................................................. 34  
3.2.2. Surface Sediments and Rocks ...................................................................................................................................... 41  
3.3. NSW AND SOUTHERN QUEENSLAND SLOPE ................................................................................................................ 49  
3.3.1. Geomorphology ............................................................................................................................................................. 49  
3.3.2. Surface Sediments and Rocks ...................................................................................................................................... 60  
3.4. ABYSSAL PLAIN/DEEP OCEAN FLOOR .......................................................................................................................... 62  
3.4.1. Geomorphology ............................................................................................................................................................. 62  
3.4.2. Surface Sediments and Rocks ...................................................................................................................................... 67
8.1. APPENDIX A: PROJECT STAFF ................................................................. 243
8.2. APPENDIX B: MAPPING PARAMETERS .................................................. 243
  8.2.1. Gravel, Sand, Mud and Carbonate Maps ............................................. 243
  8.2.2. Sediment Type – Folk Classification .................................................. 243
  8.2.3. Sediment Texture – Red/Green/Blue Image ...................................... 244
8.3. APPENDIX C: EXPLANATION OF TABLE FIELDS .............................. 245
  8.3.1. Chapter 3 Tables ............................................................................. 245
  8.3.2. Chapter 4 Tables ............................................................................. 259
  8.3.3. Chapter 5 Tables ............................................................................. 260
8.4. APPENDIX D: METADATA .................................................................... 261
8.5. APPENDIX E: DATA GENERATED .......................................................... 261
8.6. APPENDIX F: LASER GRAINSIZE DISTRIBUTIONS ......................... 261
8.7. APPENDIX G: WEB ACCESSIBLE DIGITAL MAPS FOR DATA COVERAGE AND SEDIMENT PROPERTIES .................................................... 261
List of Figures

Figure 1.1. Map showing the boundaries of the East Marine Planning Area as defined by the Department of the Environment, Water, Heritage and the Arts. The boundaries extend from the Torres Strait in the north to Montague Island in the south excluding the Great Barrier Reef Marine Park but including other reefs and the islands of Lord Howe and Norfolk. The area encompasses the ocean and seabed from the coast out to the limits of the Exclusive Economic Zone (EEZ). ................................................................. 5

Figure 1.2. Map showing the bioregions of the East Marine Region as defined by the Department of the Environment, Water, Heritage and the Arts. ......................................................... 6

Figure 2.1. The location of all quantitative textural and compositional data for the EMR stored in MARS prior to, and following, the MOU .................................................................................. 14

Figure 3.1. False-colour image of the Tasman Sea showing the geomorphology and bathymetry. The main geomorphic features are labelled. Location of features and seismic lines displayed in other figures is marked. Black line is the EMR boundary ................................................. 22

Figure 3.2. Map showing the tectonic features of the Tasman Sea and the geology of the conjugate margins. Stagg et al., (1999a); figure modified by Alcock et al., (2006) ......................... 23

Figure 3.3. Mosaic of continental block pre-breakup time (90 Ma). Blue lines are modern boundaries of the continental crust with oceanic crust. Overlap is due to synrift crustal extension. Gaina et al., 1998b .......................................................... 24

Figure 3.4. Reconstruction of the Tasman Sea opening at 67.7 Ma and at 52 Ma when spreading ceased. Gaina et al., 1998b .................................................................................. 24

Figure 3.5. Interpreted seismic profile from the Tasman Basin across the Dampier Ridge, Lord Howe Rise, New Caledonia Basin and Norfolk Ridge showing how the tectonic elements of the rifted crust, oceanic crust and volcanics determine the geomorphic features. Note the relatively steep lower slopes, the thick sediment caps on highs and sediment fill in basins. (Alcock et al., 2006) .......................................................... 25

Figure 3.6. Tectonic block reconstructions for the evolution of the plateaus, troughs and basins in the Coral Sea offshore of Queensland. Gaina et al., (1999); Exon et al., (2005) ............. 27

Figure 3.7. Profiles showing generalized basement structure and sedimentary sequences offshore of Queensland. Wellman et al., (1997) .............................................................................................. 28

Figure 3.8. Geological and tectonic interpretation of an east-west seismic profile from the Marion Plateau to the Middleton Basin. Line BMR 13/035. Location in Figure 3.44. Willcox, (1981) ......................................................................................................................... 29

Figure 3.9. Tectonic elements that form the geomorphic features in the Cato Trough – Kenn Plateau area. Exon et al., (2006b) .................................................................................... 30

Figure 3.10. Physical oceanography of the EMR, showing the main water masses influencing the region: the East Australian Current (EAC), South Equatorial Current (SEC), West Wind Drift (WWD) and inferred abyssal currents. (CSIRO; Jenkins, 1984; Kawagata, 2001). ............... 32

Figure 3.11. False colour map showing the geomorphology and bathymetry of the east Australian margin. Note the varying width of the continental shelf and continental slope and the relationship between the location of major fracture zones in the oceanic crust and shape of the continental slope. The location of seismic profiles 007 and 9 are shown. F = major fault scarps ........................................................................................................ 38
Figure 3.12. Plot of the depth of the shelf break on the eastern Australian margin. Green bars indicate a transitional zone from shelf to slope. (Boyd et al., 2004b).

Figure 3.13. Profiles of the continental shelf in the EMR normal to the shelf break from the shoreline to the shelf break. It shows the variety of depths and widths of this shelf. Approximately equally spaced from Montague Island to Fraser Island.

Figure 3.14. Seismic profile of the continental shelf and upper slope offshore of Barranjoey Head, Broken Bay, NSW, showing the relatively steep inner to mid shelf with rock outcrop and the outer shelf plain forming the top of the prograding sediment wedge. The location of the 60 m and 120 m isobaths are marked to show the location of the midshelf mud deposit. The shelf-break is gradual along this part of the coast at ~150 m. Location on Figure 3.11. Line 9A, (Heggie et al., 1992).

Figure 3.15. Seismic profile showing the carbonate platforms and sedimentary units on the outer shelf and upper slope offshore of Fraser Island (Marshall et al., 1998).

Figure 3.16. Maps showing the distribution of grain size of surface sediment on the continental shelf and upper slope south of 32° S. (Davies, 1979).

Figure 3.17. Maps showing the distribution of grain size of surface sediments on the continental shelf and upper slope from Fraser Island to 32°S. (Marshall, 1980).

Figure 3.18. Maps showing the distribution of calcium carbonate (weight %) in surface sediments on the continental shelf and upper slope from Fraser Island to 32°S. (Marshall, 1980).

Figure 3.19. a) Distribution of morphological units and location of profiles, central NSW. Boyd et al., 2004. b) Distribution of morphological units and location of profiles, northern NSW. (Boyd et al., 2004).

Figure 3.20. Bathymetric map offshore of Fraser Island showing the distribution of sedimentary facies on the shelf and upper slope around North Gardner Bank and Gardner Bank. (Marshall et al., 1998).

Figure 3.21. Line drawings of interpreted seismic profiles from the southern NSW slope and adjacent abyssal plain showing the relationship of sediments to basement. Note the convex upper slope with sediment wedge, concave mid-slope with erosion or sediments behind an outer ridge and a rugged and steep lower slope. BMR Survey 68, (Colwell et al., 1993).

Figure 3.22. Profiles of the slope from the shelf break to the abyssal plain. A range of widths and slopes occur on this margin. Profiles are approximately equally spaced from Montague Island to Fraser Island.

Figure 3.23. Seismic profile from Yamba, NSW, across the Tasman Basin to the Dampier Ridge. It shows the wide slope, lack of rise, abyssal plain and the rise at the foot of the Dampier Ridge. Note the drift deposit on the abyssal plain/deep ocean floor and the basement seamount. Location on Figure 3.1. (Van der Beuque et al., 2003).

Figure 3.24. Oblique view of the slope off Jervis Bay looking up slope to the west. Note the canyons in upper slope, mid slope terrace and large canyons. Other features are domed hills of resistant igneous rocks (I), scarps (S) and slide blocks (B). The scarp at base of slope is a major feature. V.E. 6x. Location on Figure 3.11.

Figure 3.25. Oblique view looking up slope off Wollongong to the west. Note the rock outcrop (R) on the upper slope, slide scars (S). The slide on the left is in the sediment wedge whereas the larger slide is on the seaward face of the basement outcrop. V.E. 6x. Location on Figure 3.11.
Figure 3.26. Oblique view of Mt Woolnough on the upper slope offshore of Sydney looking southwest. Note the erosion moat and depositional lobes down to 800 m water depth around the bedrock due to the EAC. V.E. 6x. Location on Figure 3.11.................................58

Figure 3.27. Oblique view looking north up slope off Newcastle to the northwest. Note the small canyons (Hunter Canyons) and slumps in the upper slope sediment wedge. They feed into wide box-canyons on the mid-slope. The lower slope is rugged with linear (fault?) scarps. The canyon on the left (Newcastle Canyon) has incised into a fan at the base of slope. Note the offset of the lower slope to the east at the top right of image. V.E. 6x. Location on Figure 3.11.................................................................58

Figure 3.28. Oblique view enlargement of Figure 3.27 showing the Hunter Canyons incised in the upper slope sediment wedge. They feed into the wide box canyon in the mid and lower slope. Isolated round peaks are interpreted as volcanic (V). Slide scars (S) and displaced blocks (B) indicate headward erosion of the box-canyon. V.E. 6x.........................................................59

Figure 3.29. Oblique view enlargement of Figure 3.27 showing slope failure in toe of the sediment wedge (S = slide scars), debris flow (D), displaced blocks (B) and volcanic ridges and pinnacles (V). V.E. 6x.................................................................59

Figure 3.30. Seismic profile across the slope illustrated in Figure 3.29. Note the upper slope sediment wedge, slide scar, older rift sediment basin in the mid slope with a volcanic ridge exposed on the down slope side. Location on Figure 3.11. Line 007, Glenn et al., (2007).........62

Figure 3.31. Seismic profile to the south-east of Newcastle showing the flat, near horizontal abyssal plain formed by turbidites and the sharp contact with the abyssal hills draped with pelagic sediments of the deep ocean floor region. Basaltic basement outcrops as small seamounts or where sediment is eroded. Location is on Figure 3.1. Eltanin Line 54. ...............65

Figure 3.32. Seismic profile from the shelf off Newcastle across the Tasman Basin to the southern Lord Howe Rise. a) The seismic profile to the east of Newcastle shows the flat slightly convex-up abyssal plain. Note the broad moats at the base of the small seamounts of basement rock and b) Pelagic sediments in the eastern part of the basin show draping on underlying basement topography and erosion adjacent to basement ridges. Note the scarp and the erosion moat at the base of the Monawai Ridge which forms the western margin of the Lord Howe Rise at this location. The Tasman Basin seabed along this transect is mostly in a narrow depth range from 4,800 to 4,900 m. Location is on Figure 3.1. Eltanin Line 47A...65

Figure 3.33. Seismic profile in the north Tasman Basin from east of Tweed Heads to the Dampier Ridge passing over Britannia Seamount. Note the wide mid-slope and steep lower slope with erosion moat at its base in the abyssal plain. Deposition by bottom currents has formed a sediment drift and apron at the base of seamount. There is an erosion moat on the east side of Britannia Seamount. Location is on Figure 3.1. Eltanin Line 29. .................................................................66

Figure 3.34. Seismic profile showing abyssal plain turbidites in sharp contact with the steep margin of the Kenn Plateau north Tasman Basin. Note the sediment blanket on the plateau. Location is on Figure 3.1. Line 270-7, Exon et al., (2005).................................66

Figure 3.35. Seismic profile showing sediment slumping from the Marion Plateau and relatively shallow turbidites forming the abyssal plain, north Tasman Basin. Note the location of the Cato Fracture Zone separating oceanic crust from continental crust. Location is on Figure 3.1. Line 1. Exon et al., (2005).................................................................67

Figure 3.36. Multibeam bathymetric map of Fraser Seamount showing it to be a guyot with a flat summit and steep sides with two prominent benches at 1,000-1,100 and 1,300-1,400m. Location on Figure 3.1. Exon et al., (2005).................................71
Figure 3.37. Seismic profile of Fraser Seamount showing an apron of slump material at its base merging with the Tasman abyssal plain. Location on Figure 3.1. Exon et al., (2005). ........................................ 72
Figure 3.38. Seismic profile across Cato Seamount showing erosion, exposure of bedrock, sediment drifts and carbonate reef as a cap on the volcanic peak. Location on Figure 3.1. Line 3, Exon et al., (2005). ........................................................................................................................................... 72
Figure 3.39. False colour image showing bathymetric features including Dampier Ridge, Lord Howe Rise, Middleton Basin, Lord Howe Basin, Lord Howe seamount chain, Monawai Ridge and Flinders Seamount. Location of other figures is marked by a white line. Black line is the EMR boundary. DSDP/ODP drill sites are shown. ....................................................................................................................... 76
Figure 3.40. a) Seismic profile across the northern Lord Howe Rise showing more topographic relief and volcanic seamounts along the western margin. Line SO30A-06/06A Willcox and Sayers (2002), b) Seismic profile across Lord Howe Basin and central Lord Howe Rise showing abyssal plain in the basin and steep volcanic western flank of the rise. Line 15/15A. Willcox and Sayers (2002) and c) Seismic line from the Tasman Basin across the Monawai Ridge and southern Lord Howe Rise. Note the steep volcanic ridge forming the margin of the plateau and the topographic relief on the rise mimicking the underlying basement. Line LHRNR-E. Stagg et al., (2002). .......................................................... 77
Figure 3.41. Multibeam bathymetry showing a series of fault scarps of the Vening-Meinesz Fracture Zone where it crosses the central part of the Lord Howe Rise. Located on the margin of the EMR but continues to the NW into the EMR. Volcanic seamounts also outcrop. Location DR08 in Figure 3.39. Colwell et al., (2006) ............................................................... 78
Figure 3.42. Seismic profile across the Vening-Meinesz Fracture Zone on the Lord Howe Rise showing erosion by bottom currents at the base of volcanic ridges. Location on Figure 3.39. Colwell et al., (2006) ........................................................................................................................................... 80
Figure 3.43. Seismic profile showing bottom simulating reflector (BSR) in Capel Basin, western flank of Lord Howe Rise and location of cores. Note the seafloor is irregular above subsurface domes. Location on Figure 3.39. GA line 206/04, Colwell et al., (2006) ........................................ 80
Figure 3.44. False colour image showing geomorphic features of the Cato Trough, Cato Basin, Kenn (Chesterfield) Plateau, Mellish Rise, Marion Plateau and associated reefs. Locations of features and seismic lines displayed in other figures are marked. Black line is the EMR boundary. ........................................................................................................................................... 83
Figure 3.45. False colour image showing geomorphic features of the Queensland Plateau, Townsville Trough, Queensland Trough, Osprey Embayment, Eastern Plateau and associated reefs. Locations of DSDP drill sites are indicated. Black line is the EMR boundary. ........................................................................................................................................... 84
Figure 3.46. a) Seismic profile across the northern Marion Plateau carbonate platform adjacent to the Townsville Trough. Note the sharp break at the platform edge and the erosion and drift deposits on the slope. The sediments beneath the seabed are interpreted as barrier reef (BR), lagoon (L), patch reef (PR) and forereef periplatform (P). (Davies et al., 1989), b) Seismic profile across the southern part of the northern Marion Plateau showing location and results of ODP drill sites. (Isern et al., 2004) and c) Seismic profile across the central part of the northern Marion Plateau from west to east. (Isern et al., 2004) ........................................................................................................................................... 85
Figure 3.47. Seismic profile across the Cato Trough showing erosion, exposure of bedrock, sediment slumps on the slopes and turbidites in floor of trough. Line 11. Location in Figure 3.44. Exon et al., (2005) ........................................................................................................................................... 86
Figure 3.48. Seismic profile across the Observatory Basin, Coriolis Ridge and Chesterfield Trough showing general drape of pelagic sediments. Line 270-3. Location in Figure 3.44. Exon et al., (2005) .................................................................86

Figure 3.49. Seismic profile from Selfridge Rise to Mellish Rise showing the trough and ridge topography typical in this area. Line GA274/01. Location in Figures 3.44 and 3.45. Exon et al., (2006a) .................................................................86

Figure 3.50. Multi-beam 3D imagery of bedforms, erosion and outcrop patterns on the Mellish Rise.a and b) Flat seabed with sand dunes (wavelength of 300 m) and outcrop with erosional moats, c and d) Volcanic cones and tilted basement ridges and e) volcanic cones, domes and lava flows. Locations in Figure 3.44 and 3.45. Exon et al., (2006) .........................................................93

Figure 3.51. Seabed photos from the Cato Pass showing active ripple marks in sand and blocks of rock with organism bending in the current. BC1, Location in Figure 3.44. Walker, (1992) .......94

Figure 3.52. Seabed photos from the eastern side of the Cato Trough showing active mounds and tracks in muddy sand and rounded boulders draped with sediment. BC2, Location in Figure 3.44. Walker, (1992) .................................................................94

Figure 3.53. Seabed photos from the central Cato Trough showing bioturbated sediment and mounds with sponge and other epifauna. BC3, Location in Figure 3.44. Walker, (1992) .......94

Figure 3.54. False colour image showing the geomorphic features around Norfolk Island. Locations of DSDP drill sites and of features and seismic lines displayed in figures 3.55 and 3.58 are marked. Black line is the EMR boundary .................................................................97

Figure 3.55. Seismic profile from the Norfolk Ridge to the eastern margin of the EMR showing the slope up from the New Caledonia Basin and the rugged topography of the ridges, troughs and plateaus. Location in Figure 3.54. Alcock et al., (2006) .................................................................97

Figure 3.56. a) Seismic profile from Lord Howe Rise across the South Fairway Basin to the Northern West Norfolk Ridge showing hills in the basin and steep ridges and b) Seismic profile from the New Caledonia Basin to Norfolk Ridge showing volcanic cones, sediment drifts and slumping. Lines 232-7A and 7B, Exon et al., (2004b) .................................................................99

Figure 3.57. Profile of North West Norfolk Ridge showing rough topography on ridge, steep lower slope and flat floor of the Fairway Basin. Location in Figure 3.54. Colwell, (2006) ......100

Figure 3.58. Seismic profile at eastern flank of central Fairway Basin, showing the distinctive bottom simulating reflector (BSR) and location of cores. GA line 177/LHRNR-BA, Location in Figure 3.54. Colwell et al., (2006) .................................................................100

Figure 4.1. a) Geomorphic Provinces of the East Marine Region (EMR); and b) Percentage area of each geomorphic province within the EMR and EEZ .................................103

Figure 4.2. a) Geomorphic Features of the East Marine Region (EMR); and b) Percentage area of each geomorphic feature within the EMR and EEZ .................................105

Figure 4.3. Distribution of water depth classes by percentage area within the East Marine Region in comparison to water depths of the whole EEZ .................................................................107

Figure 4.4. Distribution of water depths for a) reefs, b) deep/hole/valleys, c) basins and d) pinnacles in the EMR and the contribution of these to the total area of each feature in the EEZ ..................................................................................................................109

Figure 4.5. a) Sample density distribution across the EMR, and b) Frequency distribution of sample density .........................................................................................111

Figure 4.6. Sample density in each geomorphic province and feature of the EMR (y axis shows average density measured as samples per 1,000 km²) .................................................................112

Figure 4.7. Sample density in each water depth class for the entire EEZ (sample density measured as samples per 1,000 km²) ..........................................................................................112
Figure 4.8. Textural composition (mud:sand:gravel ratio) of sediments within the EMR........................... 115
Figure 4.9. Carbonate content of the a) bulk fraction; b) mud fraction; and c) sand fraction; and d) gravel fraction of sediments in the EMR........................................................................................................ 116
Figure 4.10. a) Distribution of mud in the EMR; b) % area of mud classes within the EMR  
edefined from interpolated data.................................................................................................................. 117
Figure 4.11. a) Distribution of sand in the EMR; b) % area of sand classes within the EMR  
edefined from interpolated data.................................................................................................................. 118
Figure 4.12. a) Distribution of gravel in the EMR; b) % area of gravel classes within the EMR  
edefined from interpolated data.................................................................................................................. 119
Figure 4.13. a) Distribution of bulk carbonate in the EMR; b) % area of carbonate content classes  
within the EMR derived from interpolated data.......................................................................................... 120
Figure 4.14. a) Distribution of folk classified sediments in the EMR; b) % area of folk classes  
within the EMR derived from interpolated data.......................................................................................... 122
Figure 4.15. Textural composition (mud:sand:gravel ratio) for geomorphic provinces in the EMR,  
a) shelf; b) slope; and c) abyssal plain/deep ocean floor. ........................................................................ 125
Figure 4.16. Carbonate content for geomorphic provinces in the EMR, a) shelf; b) slope; and c)  
abyssal plain/deep ocean floor.................................................................................................................. 126
Figure 4.17. Textural composition (mud:sand:gravel ratio) of geomorphic features in the EMR,  
a) deepwater trench/trench; b) shallow water terrace; c) deepwater terrace; d) plateau; e)  
plateaus on the shelf or near the shelf break; f) offshore plateaus and terraces; and g)  
terraces located on or near the shelf break.............................................................................................. 131
Figure 4.18. Carbonate content of geomorphic features in the EMR, a) shelf (unassigned); b)  
slope (unassigned); c) abyssal plain/deep ocean floor; d) plateau; e) terrace; and f)  
trench/trench ........................................................................................................................................... 133
Figure 5.1. Distribution of sediment samples in the EMR bioregions. .................................................. 135
Figure 5.2. Textural composition (mud:sand:gravel ratio) of sediments in shelf bioregions of the  
EMR......................................................................................................................................................... 136
Figure 5.3. Textural composition (mud:sand:gravel ratio) of sediments in offshore bioregions of  
the EMR, a) the Central Eastern Transition, Kenn Province, and Kenn Transition; b) Cape  
Province and Central Eastern Province; and c) Northeast Province and Northeast  
Transition. .................................................................................................................................................... 138
Figure 5.4. a) Geomorphology of the Central Eastern Shelf Province (CESP) with location of  
sediment samples; and b) Percentage area of each geomorphic feature within the CESP  
with number of corresponding sediment samples (on top of columns). ........................................... 140
Figure 5.5. Distribution of water depth classes by percentage area within the CESP.  
................................................................................................................................................................... 140
Figure 5.6. Textural composition (mud:sand:gravel ratio) of: a) shallow water terrace sediments;  
b) shelf sediments; and c) slope sediments, of the CESP........................................................................ 143
Figure 5.7. Carbonate content of: a) shallow water terrace sediments; b) shelf sediments; and c)  
slope sediments, of the CESP.................................................................................................................. 144
Figure 5.8. a) Geomorphology of the Central Eastern Shelf Transition (CEST) with location of  
sediment samples; and b) Percentage area of each geomorphic feature within the CEST  
with number of corresponding sediment samples (on top of columns). ........................................... 146
Figure 5.9. Distribution of water depth classes by percentage area within the CEST.  
................................................................................................................................................................... 146
Figure 5.10. Textural composition (mud:sand:gravel ratio) of a) shallow water terrace  
sediments; b) shelf sediments; and c) slope sediments, from the CEST.................................................. 149
Figure 5.11. Carbonate content of a) shallow water terrace sediments; b) shelf sediments; and c)  
slope sediments, for the CEST.................................................................................................................. 150
Figure 5.12. a) Geomorphology of the Southeast Shelf Transition (SEST) with location of sediment samples; and b) Percentage area of each geomorphic feature within the SEST with number of corresponding sediment samples (on top of columns). ........................................152
Figure 5.13. Distribution of water depth classes by percentage area within the SEST ........................................152
Figure 5.14. Textural composition (mud:sand:gravel ratio) of shelf sediments within the SEST. ........153
Figure 5.15. Carbonate content of shelf sediments within the SEST. .................................................................153
Figure 5.16. a) Geomorphology of the Cape Province (CP) with location of sediment samples; and b) Percentage area of each geomorphic feature within the CP with number of corresponding sediment samples (on top of columns). ........................................156
Figure 5.17. Distribution of water depth classes by percentage area within the CP ........................................156
Figure 5.18. Textural composition (mud:sand:gravel ratio) of slope sediments within the CP. ........158
Figure 5.19. Carbonate content of slope sediments within the CP ........................................................................159
Figure 5.20. a) Geomorphology of the Central Eastern Province (CEP) with location of sediment samples; and b) Percentage area of each geomorphic feature within the CEP with number of corresponding sediment samples (on top of columns) ........................................161
Figure 5.21. Distribution of water depth classes by percentage area within the CEP ........................................161
Figure 5.22. Textural composition (mud:sand:gravel ratio) of slope sediments within the CEP. ........164
Figure 5.23. Carbonate content of a) slope; and b) abyssal plain/deep ocean floor sediments within the CEP. ......................................................................................................................164
Figure 5.24. a) Geomorphology of the Central Eastern Transition (CET) with location of sediment samples; and b) Percentage area of each geomorphic feature within the CET with number of corresponding sediment samples (on top of columns). ........................................166
Figure 5.25. Distribution of water depth classes by percentage area within the CET ........................................167
Figure 5.26. Textural composition (mud:sand:gravel ratio) of terrace sediments within the CET. ........169
Figure 5.27. Carbonate content of: a) slope; and b) terrace sediments within the CET. ........................................169
Figure 5.28. a) Geomorphology of the Kenn Province (KP) with location of sediment samples; and b) Percentage area of each geomorphic feature within the KP with number of corresponding sediment samples (on top of columns). ........................................171
Figure 5.29. Distribution of water depth classes by percentage area within the KP ........................................172
Figure 5.30. Textural composition (mud:sand:gravel ratio) of plateau sediments within the KP. ........173
Figure 5.31. Carbonate content of plateau sediments within the KP ....................................................................174
Figure 5.32. a) Geomorphology of the Kenn Transition (KT) with location of sediment samples; and b) Percentage area of each geomorphic feature within the KT with number of corresponding sediment samples (on top of columns). ........................................176
Figure 5.33. Distribution of water depth classes by percentage area within the KT ........................................176
Figure 5.34. Textural composition (mud:sand:gravel ratio) of plateau sediments within the KT. ........179
Figure 5.35. Carbonate content of plateau sediments within the KT ....................................................................179
Figure 5.36. a) Geomorphology of the Norfolk Island Province (NIP) with location of sediment samples; and b) Percentage area of each geomorphic feature within the NIP with number of corresponding sediment samples (on top of columns). ........................................182
Figure 5.37. Distribution of water depth classes by percentage area within the NIP ........................................182
Figure 5.38. a) Geomorphology of the Northeast Province (NEP) with location of sediment samples; and b) Percentage area of each geomorphic feature within the NEP with number of corresponding sediment samples (on top of columns). ........................................186
Figure 5.39. Distribution of water depth classes by percentage area within the NEP ........................................186
Figure 5.40. Textural composition (mud:sand:gravel ratio) of a) slope; b) trench/trough; and c) plateau sediments within the NEP ........................................................................................................191
Figure 5.41. Carbonate content of a) slope; b) trench/trough; c) basin; and d) plateau sediments within the NEP.

Figure 5.42. a) Geomorphology of the Lord Howe Province (LHP) with location of sediment samples; and b) Percentage area of each geomorphic feature within the LHP with number of corresponding sediment samples (on top of columns).

Figure 5.43. Distribution of water depth classes by percentage area within the LHP.

Figure 5.44. Textural composition (mud:sand:gravel ratio) of plateau sediments within the LHP.

Figure 5.45. Carbonate content of plateau sediments within the LHP.

Figure 5.46. a) Geomorphology of the Northeast Transition (NET) with location of sediment samples; and b) Percentage area of each geomorphic feature within the NET with number of corresponding sediment samples (on top of columns).

Figure 5.47. Distribution of water depth classes by percentage area within the NET.

Figure 5.48. Textural composition (mud:sand:gravel ratio) of trench/trough sediments within the NET.

Figure 5.49. Carbonate content of a) trench/trough and b) plateau sediments within the NET.

Figure 5.50. a) Geomorphology of the Southeast Transition (SET) with location of sediment samples; and b) Percentage area of each geomorphic feature within the SET with number of corresponding sediment samples (on top of columns).

Figure 5.51. Distribution of water depth classes by percentage area within the SET.

Figure 5.52. a) Geomorphology of the Tasman Basin Province (TBP) with location of sediment samples; and b) Percentage area of each geomorphic feature within the TBP with number of corresponding sediment samples (on top of columns).

Figure 5.53. Distribution of water depth classes by percentage area within the TBP.

Figure 5.54. Carbonate content of abyssal plain/deep ocean floor sediments within the TBP.
List of Tables

Table 1.1. Summary details of the provincial bioregions contained in the EMR ........................................3
Table 2.1. List of geomorphic provinces and features represented in the NWMP (Heap and Harris, in press). Original definitions are adapted from IHO (2001), except for sand waves and sand banks, which are from Ashley et al. (1990). ........................................................................................................8
Table 2.2. Metadata for sediment samples with either carbonate and/or grainsize data in the EMR in MARS database following the task.................................................................10
Table 2.3. Metadata for sediment samples in the EMR procured and analysed for task...............15
Table 2.4. Criteria for assessing significance of geomorphic features in the EMR or Provincial Bioregion...................................................................................................................................17
Table 3.1. Location of canyon heads that reach the 200-300 m isobath.............................................50
Table 3.2. Seamounts of the Tasmanid and Lord Howe Chains within the EMR. Data from Slater and Goodwin, (1973), McDougal and Duncan (1988) and Royal Australian Hydrographic Office ..............................................................................................................69
Table 4.1. Statistics of geomorphic provinces and features of the EMR..............................................106
Table 4.2. Description of average density per geomorphic provinces and features containing samples.........................................................................................................................113
Table 5.1. Description of change in sample coverage in bioregions with task ................................136
Table 5.2. The percentage area of geomorphic units found in the Central Eastern Shelf Province..140
Table 5.3. The water depth of geomorphic units found in the Central Eastern Shelf Province.....141
Table 5.4. The percentage area of geomorphic units found in the Central Eastern Shelf Transition.................................................................................................................................147
Table 5.5. The water depth of geomorphic units found in the Central Eastern Shelf Transition....147
Table 5.6. The percentage area of geomorphic units found in the CP .............................................157
Table 5.7. The water depth of geomorphic units in the Cape Province.............................................157
Table 5.8. The percentage area of geomorphic units found in the Central Eastern Province......162
Table 5.9. The water depth of geomorphic units found in the Central Eastern Province.............162
Table 5.10. The percentage area of geomorphic units found in the Central Eastern Transition.....167
Table 5.11. The water depth of geomorphic units found in the Central Eastern Transition..........167
Table 5.12. The percentage area of geomorphic units found in the Kenn Province. .................172
Table 5.13. The water depth of geomorphic units found in the Kenn Province.................................172
Table 5.14. The percentage area of geomorphic units found in the Kenn Transition.........................177
Table 5.15. The water depth of geomorphic units found in the Kenn Transition...........................177
Table 5.16. The percentage area of geomorphic units found in the Norfolk Island Province........183
Table 5.17. The water depth of geomorphic units found in the Norfolk Island Province.............183
Table 5.18. The percentage area of geomorphic units found in the Northeast Province...............187
Table 5.19. The water depth of geomorphic units found in the Northeast Province......................187
Table 5.20. The percentage area of geomorphic units found in the Lord Howe Province.............195
Table 5.21. The water depth of geomorphic units found in the Lord Howe Province....................195
Table 5.22. The percentage area of geomorphic units found in the Northeast Transition...............200
Table 5.23. The water depth of geomorphic units found in the Northeast Transition.....................200
Table 5.24. The percentage area of geomorphic units found in the Southeast Transition..............206
Table 5.25. The water depth of geomorphic units found in the Southeast Transition.....................206
Table 5.26. The percentage area of geomorphic units found in the Tasman Basin Province...........209
Table 5.27. The water depth of geomorphic units found in the Tasman Basin Province.................209
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Figure 3.3 and 3.4: Modified from Journal of Geophysical Research, 103(B6), Gaina, C., Muller, D.R., Royer, J.Y., Stock, J., Hardebeck, J. and Symonds, P., The History of the Tasman Sea: a puzzle with 13 pieces, pp.12413-12433, copyright (1998), with permission from the American Geophysical Union.

Figure 3.6: Modified from Journal of Geophysical Research, 104(B6), Gaina, C., Muller, D.R., Royer, J.Y. and Symonds, P., Evolution of the Louisiade Triple Junction, pp.12927-12939, copyright (1999), with permission from the American Geophysical Union.


Figure 3.46: Modified from AAPG Memoir, 81, A Neogene carbonate platform, slope and shelf edifice shaped by sea level and ocean currents, Marion Plateau (northeast Australia), Isern, A.R., Anselmetti, F.S. and Blum, P., In: Eberli, G.P., Masaferro, J.L. and Sarg, J.F.R. (Editors), Seismic imaging of carbonate reservoirs and systems, pp.291-307, copyright (2004), with permission from the Ocean Drilling Program, US Government Printers.
Executive Summary

This report contains a review of literature and the results of a study of the sedimentology and geomorphology of the East Marine Region (EMR). The study is a collaboration between Geoscience Australia and the Department of the Environment, Water, Heritage and the Arts (DEWHA). Data generated by this study expands the national fundamental marine samples dataset for Australia’s marine jurisdiction, with analyses completed on samples from the EMR consistent to those completed on samples from other regions. Information contained in this report will contribute to Geoscience Australia’s national work program through the creation of seascapes (surrogates for seabed habitats) for the EMR, and may be used by the Department of the Environment, Water, Heritage and the Arts to provide data to assist marine bioregional planning.

Geoscience Australia is the national repository and custodian of marine sediment data and has developed a national marine samples database (MARS; http://www.ga.gov.au/oracle/mars) that is a fundamental marine dataset for the Australian margin. This study has significantly improved the distribution of quantitative textural and composition data stored in MARS for the EMR. The principal aim of this study is to provide a regional assessment of the sedimentology and geomorphology of the EMR with the following three objectives devised:

1. Analyse seabed sediment samples (nominally 100) for quantitative grainsize distribution and carbonate content;
2. Identify sources of marine sediment samples and populate MARS with the data; and
3. Produce a report synthesizing and summarizing the oceanography, tectonic history, late Quaternary evolution, geomorphology and sedimentology of the EMR based on these data and previous literature.

Results of the analyses are presented as a regional synthesis, within the framework of the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) and National Bioregionalisation of Australia 2005, and where possible within the constraints of geomorphic features identified in a recent study of the geomorphology of the Australian margin by Heap and Harris (in press). Reporting the results in this way provides both an up-dated and quantitative analysis of the regional sedimentology from previous work, and characterises the broad-scale management zones designed to support marine bioregional planning. Characterising sedimentology by geomorphic feature allows the resolution of relationships between feature and sediment type.

Oceanography, tectonic history, late Quaternary evolution and geomorphology have established the sedimentary setting for the eastern Australian margin. Fourteen bioregions occur within the EMR. Productivity is generally low due to a lack of widespread upwelling. The Southern Tropical Convergence and the Tasman Front are water mass boundaries that occur in the EMR. The East Australian Current (EAC) is the principal current and affects the composition and texture of bottom sediments on the outer shelf and upper slope. Long-shore drift of inner shelf sediments to the north is significant compared to other margins. There is also evidence for present-day deep-water currents eroding and depositing sediments. Sea level changes during the Quaternary mostly affected the shelves and coral reefs, though the
associated changing climatic-oceanographic conditions are also preserved as cycles in the deep-sea sedimentary record.

The first-order geomorphic features in the EMR are fault-bounded slopes, ridges and plateaus with steep lower slopes. This reflects the nature of the continental breakup into tectonic blocks by faulting in the late Cretaceous. Rifting and seafloor spreading formed the abyssal troughs and basins between these continental blocks and enabled large canyons to be cut on the slopes. Volcanism since the cessation of spreading has produced numerous volcanic edifices of basalt, some with over 4 km of relief. Active erosion by gravity on the slopes over geologic time has formed slump scars, canyons and valleys of all sizes and relatively low rates of sedimentations have draped, but not buried, these features. Since the Miocene, calcareous organisms have constructed large limestone platforms, particularly on the Queensland and Marion Plateaus.

The regional sedimentology is dominated by marine carbonates. The EMR extends from a tropical carbonate margin in the north to a mixed terrigenous-carbonate margin in the south that comprises shelf, slope, rise and deep ocean floor. Pelagic sedimentation dominates seaward of this margin on plateaus, seamounts, volcanic ridges and abyssal plain/deep ocean floor. Sediment texture and composition show a broad zoning with water depth due to changing sources, depositional processes and solution of carbonate with depth. The main sedimentary trends of the EMR are:

- The most extensive sediments are unconsolidated pelagic carbonate oozes on the plateaus, seamounts and slopes;
- Calcareous silts and clays occur at abyssal depths due to dissolution of most of the carbonate;
- Significant areas of Mn-nodules probably occur at abyssal depths.
- Living and/or fossil carbonate platforms/atolls/banks are significant as geomorphic features and producers of neritic carbonate sediment.
- Limestone platforms are significant on plateaus, ridges, faulted basement highs, volcanic seamounts and on the outer shelf.
- Quartz and clay minerals derived from terrigenous sources are significant components of the sediment along the Australian continental margin. But even here, with the exception of the inner shelf, the carbonate remains of benthic and planktic biota dominate.
- Due to current and wave energy the sediments are coarsest on the inner and outer shelf with finer sands and muds on the mid shelf and slope. Sand also occurs in deep-sea channels, troughs and on ridges where currents are active.
- Banks, mounds and ‘hardgrounds’ occur on the outer shelf/upper slope where seabed sediments are lithified by carbonate, phosphate and iron oxide minerals.
- Outcrop and boulder/scree material of basement rocks (both sedimentary and igneous) are common on slopes, seamounts, ridges and canyon sides. These rocks are often coated with Fe-Mn crusts up to twenty centimeters thick, depending on the length of time they have been exposed.

Significant outcomes of this study include:

- Production of the most up-to-date and comprehensive representation of the seabed sedimentology for the eastern Australian margin, building on existing regional sediment models;
• Production of a detailed synthesis and review of literature for the EMR;
• Quantification of regional seabed sediment characteristics and distribution in the EMR, and assessment of the sediment variability at a EMR, bioregion and geomorphic feature level;
• Production of a robust, consistent quantitative dataset that permits defensible quantitative comparisons of the seabed sedimentology to be made between the eastern margin and the whole Australian margin; and
• Recognition and quantification of the spatial heterogeneity of seabed sedimentology within the EMR that can be linked to seabed habitat complexity. Capturing the spatial heterogeneity of the seabed sedimentology will allow more accurate and precise mapping of seabed habitats (seascapes), and aids in more effective future sampling strategies.

A principal application of the study is to support research into the associations between physical seabed properties such as sediment texture and composition and the distribution of benthic marine habitats and biota. This research contributes to Geoscience Australia’s work on the spatially representation of benthic marine habitats and biota for Australia’s vast marine jurisdiction. This work is crucial for developing robust, defensible methods of mapping habitats using spatially abundant physical data combined with site-specific biological data and over thousands of kilometres.
1. Introduction

1.1. BACKGROUND

This report presents the geomorphology and sedimentology of the East Marine Region (Fig. 1.1). The three main outputs of the report include: 1) a review of previous geological research undertaken in the East Marine Region (EMR); 2) the results of a quantitative study of seabed sediment texture and composition for these regions; and 3) a synthesis of this information characterizing regional trends in sedimentology, geomorphology and bathymetry. The study is a collaboration between Geoscience Australia and the Department of the Environment, Water, Heritage and the Arts (DEWHA) and is a continuation of similar work conducted for the North West Marine Region (Potter et al., in press; Baker et al., 2008) and the South West Marine Region (Richardson et al., 2005). By combining results of previous qualitative work and quantitative information generated from existing and new data, this report provides an improved understanding of sedimentology for the EMR. Information contained within this report will contribute to the Department of the Environment, Water, Heritage and the Arts national work program and will also assist in the marine bioregional planning for the East Marine Region.

Previous sediment studies in the EMR have predominantly produced qualitative results at local scales. Geomorphic, sedimentary and biological information has previously been utilised to develop a National Bioregionalisation of Australia’s Exclusive Economic Zone (EEZ) (Department of the Environment and Heritage (National Oceans Office), 2005; now the Department of the Environment, Water, Heritage and the Arts) and substantive geomorphic features of the eastern continental margins have already been identified and mapped (Heap and Harris, in press-a). This report adds significantly to these previous studies by incorporating the information in a sedimentological synthesis that includes a discussion of the implications for marine conservation in the EMR.

The physical characteristics of the seabed in the EMR, as described by the sediment texture and composition data, can assist in determining the diversity of benthic marine habitats in the EMR. These data represent enduring features which are elements of the physical environment that do not change considerably and they are known to influence the diversity of biological systems. This is important for marine conservation by contributing to the better definition and characterisation of benthic habitats. Seabed texture and composition are easily measurable parameters that when combined with other physical features can be used to create “seascapes” that serve as broad surrogates for benthic habitats and biota (Whiteway et al., 2007). Seascapes have the potential to be used in informing the marine bioregional planning process.

1.2. SCOPE

1.2.1. Generation and Synthesis of Seabed Information for the EMR

In April 2007, Geoscience Australia and the DEWHA agreed to undertake a collaborative project to identify, analyse and collate existing information on the texture and composition of the seabed in the EMR. The main objectives of this project were to:

- Identify and summarise all previous geological information for the EMR;
• Procure and analyse sediment samples (nominally 100) from the EMR, currently held by Geoscience Australia and other marine science institutions, for grain size and carbonate concentrations;
• Provide data on the texture and composition of the seabed for the EMR to populate Geoscience Australia’s national marine samples database (MARS; www.ga.gov.au/oracle/mars) with the data; and
• Produce a report synthesising and summarising the sedimentology and geomorphology of the seabed for the EMR in support of marine bioregional planning and creation of a national system of representative marine protected areas.

Texture and composition data generated from this project will be combined with other physical data on the seabed (i.e., depth, geomorphology, sediment mobility, etc) to create “seascapes” that represent major ecological units based on measurable, recurrent and predictable features of the marine environment.

1.2.2. Expected Project Outcomes
The expected outcomes of this project are:
• To obtain a better understanding of the nature of the seabed for the eastern margin of Australia;
• To improve the available information on the sedimentology of the EMR for the scientific and planning communities, leading to the development of more effective plans for marine conservation sustainable development; and
• To improve access to data on the nature of the seabed through continued population of the MARS database as a national fundamental marine dataset.

1.2.3. Products and Outputs
Key outputs of this project will be:

• 100 quantitative textural and compositional data points for the EMR and associated metadata available in the MARS database;
• A review and synthesis of previous geological information for the EMR (Chapter 3);
• Quantitative analyses of the sedimentology and geomorphology of the EMR (Chapters 4, 5 and 6);
• A synthesis of all previous and new sediment information for the EMR at planning region and bioregion (as defined by DEWHA) scales (Chapters 4, 5 and 6);
• An interpretation of sediment information and discussion of the significant findings and their implications for Marine Bioregional Planning (Chapter 6); and
• A series of web-accessible digital maps to standards appropriate for data coverage and sediment properties in the EMR (Appendix G).

1.3. MARINE REGIONS AND BIOREGIONS
The benthic component of the NMB 2005 management framework consists of a hierarchical set of geographic management units. Below the scale of the major ocean basins that comprise Australia’s marine jurisdiction (i.e., the Indian, Southern and Pacific Oceans), the shelf, slope, rise and abyssal
plain/deep ocean floor are designated as Primary Bathymetric Units that represent the broadest-scale planning unit, and have areas of several million km². Within each of the Primary Bathymetric Units are Provincial Bioregions, which have been defined mainly by the distribution of demersal fish, bathymetry, and geomorphology, and have areas of hundreds of thousands of km². The Provincial Bioregions are the principal planning unit for Marine Bioregional Planning. Marine bioregional plans will be developed for each of Australia’s five marine regions including the EMR.

1.3.1. The East Marine Region (EMR)

The EMR adjacent to Australia includes the seabed and water column from the coastline and the boundary of the Great Barrier Reef Marine Park to the 200 nautical mile limit drawn from the territorial sea baseline, and from Bermagui in southern New South Wales to Torres Strait in the north. In addition it includes the EEZ around Lord Howe Island, Middleton and Elizabeth Reefs and the EEZ around Norfolk Island (Fig. 1.1). This region comprises 2.5 million km² of ocean and seabed and abuts the coastal waters of New South Wales and Queensland. The EMR represents around 27% of the Australian Economic Exclusive Zone (AEEZ) and includes an area of 400 km² with water depths <10 m which represents islands and reef zones and has been excluded from our assessment.

1.3.2. EMR Bioregions

The EMR comprises 14 bioregions (Figure 1.2; Table 1.1). The EMR contains part of the Central Eastern Shelf Province, part of the Central Eastern Shelf Transition, and part of the Southeast Shelf Transition. This province and transitions are located on the shelf. Water depths in the Shelf bioregions are between 10 m and 350 m, but are generally <150 m.

<table>
<thead>
<tr>
<th>Bioregion</th>
<th>% of bioregion included in EMR</th>
<th>Water type</th>
<th>% of total EMR area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cape Province</td>
<td>56</td>
<td>Tropical Waters</td>
<td>3</td>
</tr>
<tr>
<td>Central Eastern Shelf Province</td>
<td>76</td>
<td>Warm Temperate Waters</td>
<td>1</td>
</tr>
<tr>
<td>Central Eastern Shelf Transition</td>
<td>55</td>
<td>Transition</td>
<td>1</td>
</tr>
<tr>
<td>Central Eastern Province</td>
<td>88</td>
<td>Warm Temperate Waters</td>
<td>9</td>
</tr>
<tr>
<td>Central Eastern Transition</td>
<td>69</td>
<td>Transition</td>
<td>2</td>
</tr>
<tr>
<td>Kenn Province</td>
<td>100</td>
<td>Tropical Waters</td>
<td>2</td>
</tr>
<tr>
<td>Kenn Transition</td>
<td>100</td>
<td>Transition</td>
<td>15</td>
</tr>
<tr>
<td>Lord Howe Province</td>
<td>100</td>
<td>Warm Temperate Waters</td>
<td>20</td>
</tr>
<tr>
<td>Northeast Province</td>
<td>93</td>
<td>Tropical Waters</td>
<td>17</td>
</tr>
<tr>
<td>Northeast Transition</td>
<td>88</td>
<td>Transition</td>
<td>5</td>
</tr>
<tr>
<td>Southeast Shelf Transition</td>
<td>7</td>
<td>Transition</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Southeast Transition</td>
<td>4</td>
<td>Transition</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Norfolk Island Province</td>
<td>100</td>
<td>Warm Temperate Waters</td>
<td>18</td>
</tr>
<tr>
<td>Tasman Basin Province</td>
<td>100</td>
<td>Warm Temperate Waters</td>
<td>6</td>
</tr>
</tbody>
</table>
The EMR also contains the Cape Province, Central Eastern Province, Central Eastern Transition, Kenn Province, Kenn Transition, Lord Howe Province, Northeast Province, Northeast Transition, Southeast Transition, Norfolk Island Province and Norfolk Island Transition (Table 1.1). These provinces and transitions cover the slope, the rise, plateaus, seamounts and abyssal plain/deep ocean floor. They are bounded by the shelf break and water depths vary from 150 m to over 5,000 m.

Full details of the bioregions are presented in Chapter 5. To support marine bioregional planning in the EMR, the results of this study are discussed in the context of the provincial bioregions, and data are presented for individual bioregions.

1.4. REPORT AIMS AND STRUCTURE

The aim of this report is to provide a regional assessment of the sedimentology and geomorphology of the EMR. The report is structured into three broad sections: First, the existing sedimentology and geomorphology of the EMR is described and reviewed to provide a framework for new data (Chapter 3). The second section presents a regional scale spatial analysis of the sedimentology and geomorphology for the EMR (Chapter 4). The third section provides a spatial analysis of the sedimentology and geomorphology for each provincial bioregion occurring in the EMR. This section (Chapter 5) puts the new data into the context of the planning zones used by DEWHA. Lastly, results of this study and previous work in the EMR are summarised and discussed in terms of their implications for marine planning (Chapter 6).
Figure 1.1. Map showing the boundaries of the East Marine Planning Area as defined by the Department of the Environment, Water, Heritage and the Arts. The boundaries extend from the Torres Strait in the north to Montague Island in the south excluding the Great Barrier Reef Marine Park but including other reefs and the islands of Lord Howe and Norfolk. The area encompasses the ocean and seabed from the coast out to the limits of the Exclusive Economic Zone (EEZ).
Figure 1.2. Map showing the bioregions of the East Marine Region as defined by the Department of the Environment, Water, Heritage and the Arts.
2. Data and Methods

This chapter outlines the available physical data sets for the EMR and the process of acquiring additional sediment samples to fill gaps in data coverage. Chapters 2.1 – 2.3 provide details of existing quantitative physical data sets for the EMR that have been used in this study and pre-existing sediment data. Chapters 2.4 – 2.7 discuss the procedure for identifying (from both internal and external data repositories), selecting and procuring samples, and generating grainsize and carbonate data. All metadata and assays for samples used to describe quantitative sediment distribution in the EMR are contained in Geoscience Australia’s marine samples database, MARS.

2.1. EXISTING PHYSICAL DATA FOR THE EMR

2.1.1. Bathymetry

Bathymetric data for the EEZ and all smaller divisions within it were derived from classifications of the Australian Bathymetry and Topography Grid (June 2005). The grid is a synthesis of 1.7 billion observed data points and resolution at any point is equal to or better than 250 m. It provides full coverage of Australia’s EEZ including areas under Australian jurisdiction surrounding Macquarie Island, and the Australian Territories of Norfolk Island, Christmas Island, and Cocos (Keeling) Islands. The area selected does not include Australia’s marine jurisdiction off of the Territory of Heard and McDonald Islands and the Australian Antarctic Territory.

Water depths for individual sample data points and ranges for data points were sourced from original survey documentation. The metadata for these sample points did not include water depths for around 30% of the total data points used in this study. Depths for these points were generated by intersecting point data with the Australian Bathymetry and Topography Grid.

2.1.2. Geomorphology

In 2004, a collaborative agreement between Geoscience Australia, CSIRO – Marine and Atmospheric Research, and the then Department of the Environment and Heritage (National Oceans Office), created a National Marine Bioregionalisation (NMB 2005) of Australia (Department of the Environment and Heritage, 2005). The NMB 2005 provides an over-arching management framework for a large part of Australia’s marine jurisdiction, and is based on the most up-to-date knowledge of the biophysical properties of Australia’s marine environment, including seabed geomorphology and sedimentology. Definitions of geomorphic provinces and features included in the NMB 2005 and used in the spatial analyses in this study are listed in Table 2.1.

Geomorphic province and feature boundaries for the EEZ and all smaller divisions within it were derived from a recent study of the geomorphology of Australia’s margin and deep seafloor (Heap and Harris, in press). These boundaries were delineated using the 250 m bathymetry grid and previous local seabed studies. Feature names are based on those endorsed by the International Hydrographic Office (IHO 2001). Features are nested within larger geomorphic provinces of shelf, slope, rise and abyssal plain/deep ocean floor.
Table 2.1. List of geomorphic provinces and features represented in the NWMR (Heap and Harris, in press). Original definitions are adapted from IHO (2001), except for sand waves and sand banks, which are from Ashley et al. (1990).

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Geomorphic Provinces</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Shelf</td>
<td>Zone adjacent to a continent (or around an island) and extending from the low water line to a depth at which there is usually a marked increase of slope towards oceanic depths.</td>
</tr>
<tr>
<td></td>
<td>- Slope</td>
<td>Slope seaward from the shelf edge to the upper edge of a continental rise or the point where there is a general reduction in slope.</td>
</tr>
<tr>
<td></td>
<td>- Rise</td>
<td>Gentle slope rising from the oceanic depths towards the foot of a continental slope.</td>
</tr>
<tr>
<td></td>
<td>- Abyssal Plain/ Deep Ocean Floor (AP/DOF)</td>
<td>Extensive, flat, gently sloping or nearly level region at abyssal depths.</td>
</tr>
<tr>
<td></td>
<td><strong>Geomorphic Features</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Shelf (unassigned)</td>
<td>Area of Shelf Geomorphic Province in which no other geomorphic features have been identified.</td>
</tr>
<tr>
<td>2</td>
<td>Slope (unassigned)</td>
<td>Area of Slope Geomorphic Province in which no other geomorphic features have been identified.</td>
</tr>
<tr>
<td>3</td>
<td>Rise (unassigned)</td>
<td>Area of Rise Geomorphic Province in which no other geomorphic features have been identified.</td>
</tr>
<tr>
<td>4</td>
<td>AP/DOF* (unassigned)</td>
<td>Area of Abyssal Plain/ Deep Ocean Floor Geomorphic Province in which no other geomorphic features have been identified.</td>
</tr>
<tr>
<td>5</td>
<td>Bank/shoal</td>
<td>Elevation over which the depth of water is relatively shallow but normally sufficient for safe surface navigation. Offshore hazard to surface navigation that is composed of unconsolidated material.</td>
</tr>
<tr>
<td>6</td>
<td>Deep/hole/valley</td>
<td>Deep: In oceanography, an obsolete term which was generally restricted to depths greater than 6,000 m. Hole: Local depression, often steep sided, of the seabed Valley: Relatively shallow, wide depression, the bottom of which usually has a continuous gradient. This term is generally not used for features that have canyon-like characteristics for a significant portion of their extent.</td>
</tr>
<tr>
<td>7</td>
<td>Trench/trough</td>
<td>Trench: Long narrow, characteristically very deep and asymmetrical depression of the seabed, with relatively steep sides. Trough: Long depression of the seabed characteristically flat bottomed and steep sided and normally shallower than a trench.</td>
</tr>
<tr>
<td>8</td>
<td>Basin</td>
<td>Depression, characteristically in the deep seabed, more or less equidimensional in plan and of variable extent.</td>
</tr>
<tr>
<td>9</td>
<td>Reef</td>
<td>Rock lying at or near the sea surface that may constitute a hazard to surface navigation.</td>
</tr>
</tbody>
</table>
10 Canyon A relatively narrow, deep depression with steep sides, the bottom of which generally has a continuous slope, developed characteristically on some continental slopes.

11 Knoll/abyssal hills/hill/mountains/peak Knoll: Relatively small isolated elevation of a rounded shape. Abyssal Hills: Tract, on occasion extensive, of low (100-500 m) elevations on the deep seabed. Hill: Small isolated elevation. Mountain: Large and complex grouping of ridges and seamounts. Peak: Prominent elevation either pointed or of a very limited extent across the summit.

12 Ridge (a) Long, narrow elevation with steep sides. (b) Long, narrow elevation often separating ocean basins. (c) Linked major mid-oceanic mountain systems of global extent.

14 Pinnacle High tower or spire-shaped pillar of rock or coral, alone or crested a summit. It may extend above the surface of the water. It may or may not be a hazard to surface navigation.

15 Plateau Flat or nearly flat area of considerable extent, dropping off abruptly on one or more sides.

16 Saddle Broad pass, resembling in shape a riding saddle, in a ridge or between contiguous seamounts.

17 Apron/fan Apron: Gently dipping featureless surface, underlain primarily by sediment, at the base of any steeper slope. Fan: Relatively smooth, fan-like, depositional feature normally sloping away from the outer termination of a canyon or canyon system.

19 Sill Seabed barrier of relatively shallow depth restricting water movement between basins.

20 Terrace Relatively flat horizontal or gently inclined surface, sometimes long and narrow, which is bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side.

21 Tidal sandwave/sand bank Sandwave: Wave-like bed form made of sand on the sea bed. Sand bank: Submerged bank of sand in a sea or river that may be exposed at low tide.

### 2.1.3. Sediment Data

A total of 744 samples with quantitative textural and/or compositional sediment data were available in the MARS Database prior to this study for the EMR. These sample locations contained bulk carbonate, grain size (Wt%; μm) and/or laser grain size (Vol%; μm) data. The samples were sourced from 17 marine surveys conducted between 1970 and 2006 (Table 2.2), and consist of dredge, grab and core samples. Samples that occur outside of the EMR were included to supplement scarce data for the abyssal plain/deep ocean floor and slope to improve representation of geomorphic features and capture the full spectrum of environments.

All sample and assay data was quality controlled and those samples that failed to meet the minimum metadata standards outlined in Geoscience Australia’s Data standards and validation in AGSO
were excluded from the analysis. Only analyses conducted on dredges, grabs or the top 0.1 m of a core and where the gravel, sand and mud fractions totalled 100% +/- 1% were included. Core samples that did not include depth measurements were also excluded and duplicates were removed. Ongoing quality control of data may have resulted in slight variations between total samples reported in this document and milestone progress reports.

Table 2.2. Metadata for sediment samples with either carbonate and/or grainsize data in the EMR in MARS database following the task.

<table>
<thead>
<tr>
<th>Survey Name</th>
<th>Vessel</th>
<th>Year</th>
<th>Sample Types</th>
<th>No. of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geoscience Australia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern Barrier Reef &amp; Northern Tasman Sea</td>
<td>San Pedro Strait</td>
<td>1970</td>
<td>Pipe dredge</td>
<td>113</td>
</tr>
<tr>
<td>Tasman Sea and Bass Strait</td>
<td>San Pedro Strait</td>
<td>1972</td>
<td>Pipe dredge</td>
<td>141</td>
</tr>
<tr>
<td>North East Australia 1</td>
<td>Rig Seismic</td>
<td>1985</td>
<td>Dredge</td>
<td>2</td>
</tr>
<tr>
<td>North Eastern Australia Heat Flow</td>
<td>Rig Seismic</td>
<td>1986</td>
<td>Piston &amp; gravity core</td>
<td>8</td>
</tr>
<tr>
<td>East Australia Phosphates</td>
<td>Rig Seismic</td>
<td>1987</td>
<td>Gravity core</td>
<td>17</td>
</tr>
<tr>
<td>North East Australia 3</td>
<td>Rig Seismic</td>
<td>1987</td>
<td>Gravity core &amp; dredge</td>
<td>10</td>
</tr>
<tr>
<td>North East Australia 4</td>
<td>Rig Seismic</td>
<td>1987</td>
<td>Gravity &amp; piston core &amp; dredge</td>
<td>12</td>
</tr>
<tr>
<td>Southern Queensland Margin</td>
<td>Rig Seismic</td>
<td>1991</td>
<td>Gravity core, dredge &amp; grab</td>
<td>207</td>
</tr>
<tr>
<td>Continuous Geochemical Tracers</td>
<td>Rig Seismic</td>
<td>1992</td>
<td>Gravity and vibro core</td>
<td>15</td>
</tr>
<tr>
<td>Geology and Tectonic Evolution of Mellish Rise</td>
<td>Southern Surveyor</td>
<td>2005</td>
<td>Gravity core &amp; dredge</td>
<td>17</td>
</tr>
<tr>
<td>NSW Continental Slope Survey</td>
<td>Southern Surveyor</td>
<td>2006</td>
<td>Gravity core</td>
<td>12</td>
</tr>
<tr>
<td><strong>CSIRO</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedimentation at Fly River/ North Great Barrier Reef Junction, Gulf of Papua</td>
<td>Franklin</td>
<td>1993</td>
<td>Grab</td>
<td>1</td>
</tr>
<tr>
<td><strong>Lamont Doherty Earth Observatory</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vema Cruise 16, Leg 9</td>
<td>Vema</td>
<td>1960</td>
<td>Piston core</td>
<td>2</td>
</tr>
<tr>
<td>Conrad Cruise 10, Leg 6</td>
<td>Robert D Conrad</td>
<td>1966</td>
<td>Piston core</td>
<td>2</td>
</tr>
<tr>
<td>Vema Cruise 24, Leg 7 &amp; 8</td>
<td>Vema</td>
<td>1967</td>
<td>Piston core</td>
<td>16</td>
</tr>
<tr>
<td>Conrad Cruise 12, Leg 4 &amp; 5</td>
<td>Robert D Conrad</td>
<td>1968</td>
<td>Piston core</td>
<td>2</td>
</tr>
</tbody>
</table>
2.2. PREVIOUS DATA COVERAGE OF THE EMR

Prior to this study, the majority of samples within the EMR were located from the shelf and upper slope in the south west of the region within the Central Eastern Shelf Transition, Central Eastern Shelf Province, Southeast Shelf Transition, Central Eastern Province and the southern part of the Central Eastern Transition. Sparse sample coverage also existed for the remainder of the Central Eastern Province and the Lord Howe Province (Fig. 2.1). Other bioregions in the EMR contained <3 samples each. A total of 680 of the 744 pre-existing sediment samples in the EMR were located on the NSW shelf and 732 pre-existing samples were located in water depths <1,000 m. Shelf (unassigned), slope (unassigned) and shallow water terraces contained the most number of samples, while significantly fewer samples occurred in abyssal plain/deep ocean floor (unassigned), trench/trough, canyon, plateau, and saddle features. Prior to this task no samples were available for rise, deep/hole/valley, basin and seamount/guyots features in the EMR.

Highest sample density occurred on the shelf in the Central Eastern Shelf Transition, Central Eastern Shelf Province and Southeast Shelf Transition and on areas of the upper slope in the Central Eastern Province and Central Eastern Transition. In these areas, most samples occur within 0-0.025 km of the nearest sample. No samples were located in the Kenn Province and Kenn Transition.
New sample data has significantly improved the sample coverage of the Cape Province, Lord Howe Province, Northeast Province and Northeast Transition, and has provided the first quantitative data for the Kenn Province and Kenn Transition.

2.3. ASSESSMENT OF SIGNIFICANT GAPS IN EXISTING SAMPLE COVERAGE FOR THE EMR

The relationship between data coverage and the other physical variables determines the accuracy of the final interpretations of sediment distribution. The EMR contains areas where samples, for various reasons, provided insufficient coverage to estimate sediment distribution. Recognition of these gaps was used to guide sample selection for this study. A targeted approach for one addition of sediment data allows for more efficient improvement in sediment information for the EMR in the short to medium term. Similar assessment of gaps in data coverage resulting from this task (Chapters 4 & 5) will be used to guide sample collection/procurement in the future.

Three types of data gaps were identified and used to guide sample procurement for this study, namely:

- Gaps in spatial coverage. This was determined by mapping the data density across the EMR, and identifying areas in the Provincial Bioregions, Primary Bathymetric Units and Geomorphic Features where the least samples existed.
- Gaps in spatial coverage of specific features. An assessment of the distribution of samples within the area of a Provincial Bioregion, Primary Bathymetric Unit or Geomorphic Feature was conducted by assessing the coverage of the number of separate occurrences of the feature and degree to which samples are clustered within these. This determined whether assays are likely to be representative of the range and relative proportion of sediment types.
- Knowledge gaps are not always directly related to sample density. Conceptual understanding of seabed morphology in different geomorphic features and high resolution information derived from local studies and seabed images means that we can estimate the sample spacing required to map actual variations in seabed character to a given resolution. Comparison between this required sample density and the density of existing data can be used to identify areas where data are inadequate to estimate sediment properties.

2.4. SAMPLE IDENTIFICATION IN THE EMR AND SELECTION FOR ANALYSIS

2.4.1. Sample Identification

MARS database

Approximately 2,000 samples without quantitative grainsize and 4,000 samples without quantitative carbonate assays were stored in the MARS database prior to this study. The majority of these samples are located on the NSW shelf. More than 1,000 of these are contained in Geoscience Australia’s archives. The remaining samples are located in external institutions such as BGR Germany, Lamont Doherty Earth Observatory, James Cook University, Oregon State University, Scripps Institute of Oceanography, Integrated Ocean Drilling Program data repository or contain inadequate sample volumes for analysis. A large number of samples for the EMR are currently stored in the Natural
History Museum, London. Of the samples contained in Geoscience Australia’s archives 82 were sub-sampled and analysed for the task.

External Databases

Of the samples identified in external data repositories, 59 were selected that contained adequate sample volumes and filled spatial gaps in the data coverage of the EMR. These samples were located at four international institutions, namely: Oregon State University, Integrated Ocean Drilling Program Texas A&M University, Scripps Institute of Oceanography and Lamont-Doherty Earth Observatory.

2.4.2. Sample Selection

A total of 141 samples were selected for analysis for this study based on the gap analysis. These consisted of core, dredge and grab samples collected on 16 surveys conducted between 1960 and 2005 (Table 2.3). Selected samples include 82 from the Geoscience Australia data repository and 59 from external repositories.

Significant data gaps were identified in the Cape Province, Kenn Province, Kenn Transition, Lord Howe Province, Norfolk Island Province, Northeast Province, Northeast Transition, Southeast Transition and Tasman Basin Province. Sediment samples increase coverage of all bioregions except for the Southeast Transition and shelf bioregions where previous sample coverage was high.

Significant spatial data gaps were identified in deep water areas especially in water depths of >3,000 m. The addition of samples to deep water geomorphic features, including the lower slope, basin, and trench/trough has significantly improved the representation of deep water environments. While this study has improved the sample coverage of geomorphic features within the EMR, significant gaps still exist. No samples are currently available that represent bank/shoal, reef, knoll/abyssal hills/hill/mountains/peak, ridge, pinnacle, and apron/fan within the EMR. Eleven samples have been collected in deep water areas beyond the EMR boundary and these have been used to help characterise the sedimentology of the abyssal plain/deep ocean floor and lower slope within the EMR.
Figure 2.1. The location of all quantitative textural and compositional data for the EMR stored in MARS prior to, and following, the MOU.
Table 2.3. Metadata for sediment samples in the EMR procured and analysed for task.

<table>
<thead>
<tr>
<th>Survey Name</th>
<th>Vessel</th>
<th>Year</th>
<th>Sample Types</th>
<th>No. of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geoscience Australia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Eastern Australia Heat Flow</td>
<td>Rig Seismic</td>
<td>1986</td>
<td>Piston &amp; gravity core</td>
<td>7</td>
</tr>
<tr>
<td>East Australia Phosphates</td>
<td>Rig Seismic</td>
<td>1987</td>
<td>Gravity core</td>
<td>6</td>
</tr>
<tr>
<td>North East Australia 3</td>
<td>Rig Seismic</td>
<td>1987</td>
<td>Gravity core &amp; dredge</td>
<td>10</td>
</tr>
<tr>
<td>North East Australia 4</td>
<td>Rig Seismic</td>
<td>1987</td>
<td>Gravity &amp; piston core &amp; dredge</td>
<td>12</td>
</tr>
<tr>
<td>Southern Queensland Margin</td>
<td>Rig Seismic</td>
<td>1991</td>
<td>Gravity core, dredge &amp; grab</td>
<td>4</td>
</tr>
<tr>
<td>Continuous Geochemical Tracers</td>
<td>Rig Seismic</td>
<td>1992</td>
<td>Gravity and vibro core</td>
<td>15</td>
</tr>
<tr>
<td>Geology and Tectonic Evolution of Mellish Rise</td>
<td>Southern Surveyor</td>
<td>2005</td>
<td>Gravity core &amp; dredge</td>
<td>17</td>
</tr>
<tr>
<td><strong>Lamont Doherty Earth Observatory</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vema Cruise 16, Leg 9</td>
<td>Vema</td>
<td>1960</td>
<td>Piston core</td>
<td>2</td>
</tr>
<tr>
<td>Conrad Cruise 10, Leg 6</td>
<td>Robert D Conrad</td>
<td>1966</td>
<td>Piston core</td>
<td>2</td>
</tr>
<tr>
<td>Vema Cruise 24, Leg 7 &amp; 8</td>
<td>Vema</td>
<td>1967</td>
<td>Piston core</td>
<td>16</td>
</tr>
<tr>
<td>Conrad Cruise 12, Leg 4 &amp; 5</td>
<td>Robert D Conrad</td>
<td>1968</td>
<td>Piston core</td>
<td>2</td>
</tr>
<tr>
<td>Vema Cruise 33, Leg 14</td>
<td>Vema</td>
<td>1977</td>
<td>Piston core</td>
<td>1</td>
</tr>
<tr>
<td><strong>Ocean Drilling Program</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean Drilling Program, Leg 133 &amp; 194</td>
<td>Joides Resolution</td>
<td>1990</td>
<td>Core (unspecified)</td>
<td>18</td>
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<tr>
<td><strong>Oregon State University</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global Expedition of RV Oceanographer</td>
<td>Oceanographer</td>
<td>1967</td>
<td>Piston core</td>
<td>5</td>
</tr>
<tr>
<td><strong>Scripps Institute of Oceanography</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LUSIAD Leg 5, NOVA Leg 4 &amp; 5</td>
<td>Horizon</td>
<td>1963</td>
<td>Gravity core</td>
<td>13</td>
</tr>
</tbody>
</table>
2.5. SAMPLE ACQUISITION AND ANALYSIS

Samples from repositories outside Australia were sent to Geoscience Australia. Between 12 and 50 g of sediment were used for grainsize and carbonate analyses. Each sample was analysed as follows:

- **Grainsize (Vol%; μm):** The grainsize distribution of the 0.01–2,000 μm fraction of the bulk sediment was determined with a Malvern Mastersizer 2000 laser particle analyser. All samples were wet sieved through a 2,000 μm mesh to remove the coarse fraction. A minimum of 1 g was used for samples comprising relatively fine material and between 2–3 g for samples comprising relatively coarse material. Samples were ultrasonically treated to help disperse the particles. Distributions represent the average of three runs of 30,000 measurement snaps that are divided into 100 particle size bins of equal size.

- **Grainsize (Wt%):** Gravel, sand, and mud concentrations were determined by passing 10–20 g of bulk sediment through standard mesh sizes (Gravel >2,000 μm; Sand 63 μm-2,000 μm; Mud <63 μm). The resulting gravel, sand, and mud concentrations represent dry weight proportions.

- **Carbonate content (Wt%):** Bulk, sand and mud carbonate concentrations were determined on 2–5 g of material using the ‘Carbonate bomb’ method of Muller and Gastner (1971). Carbonate gravel concentrations were determined by visual inspection.

All analyses were conducted by the Palaeontology and Sedimentology Laboratory at Geoscience Australia. Where sample volumes were insufficient to complete all analyses, laser grainsize and bulk carbonate were completed as a priority. Further information on the data analysis is available in Appendix C.

2.6. ASSESSMENT OF SIGNIFICANT GEOMORPHIC FEATURES

Analysis of sediment type and distribution has been completed at Planning Region and Bioregion scales. Within these regions, analysis has also been completed for features identified as ‘significant’. Significant features are defined as single or groups of geomorphic features that characterise the seabed, and therefore represent potentially significant areas for conservation within that region/at that scale that are based on a set of criteria (Table 2.4). Significant features have been identified for the EMR and individual bioregions within it. Significance of features could not be assessed at international scales as equivalent datasets are not available for areas outside of the AEEZ. Where a feature (significant or otherwise) contained <3 samples, quantitative analysis of sedimentology within this feature was not undertaken due to the low number of samples. Sedimentology for significant features without adequate quantitative data is, where possible, described from previous studies.
Table 2.4. Criteria for assessing significance of geomorphic features in the EMR or Provincial Bioregion.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature is best represented in EMR or Bioregion</td>
<td>Feature covers significant area of the EMR or bioregion OR Feature is not abundant elsewhere in Australia’s EEZ (significant portion of total area of this feature occurs in EMR or bioregion)</td>
</tr>
<tr>
<td>Feature is unique to EMR or Bioregion</td>
<td>This occurrence has a physical attribute i.e: -extent -sedimentology -bathymetry -latitude that differs from that of other occurrences of this feature in the EMR or EEZ</td>
</tr>
</tbody>
</table>

2.7. MAP PRODUCTION

2.7.1. Percent Gravel/Sand/Mud and Folk Classification and Percent Carbonate

Maps for %Gravel, %Sand, %Mud, Folk Classification, and %Carbonate were clipped from rasters created for the entire EEZ. These were created by:

- Querying the MARS database to obtain all numeric grainsize and carbonate content data for Australia’s EEZ and any samples located outside the EEZ but within 100 km of the boundary;
- Compiling the results into gravel, sand and mud fractions (%), mean grainsize (μm) and carbonate (%);
- Checking that gravel, sand and mud for each sample had all three fractions reported, and that these fractions were in the appropriate range when summed (100 +/- 1%); and then
- Checking for and resolving cases of duplication.

The sediment classification proposed by Folk (1954) has been used to present information on sediment type. Sediment fraction interpolations were combined into a single raster file and values for each cell at 0.05 decimal degree resolution were exported as points. Folk classes were defined from Folk (1954) diagram and a script automating classification based on these definitions was written in Pearl. This script was applied to the to exported point data. Classified cell values were imported back into ArcGIS for map production. Areas for classes on all interpolated maps are calculated only for the interpolated area that lies within the EMR.