4. Quantitative Description of the NWMR and NNMR

4.1. QUANTITATIVE DESCRIPTION OF THE NWMR

4.1.1. Geomorphology

Four geomorphic provinces occur in the NWMR (Fig. 4.1; Table 4.1). The slope makes up the largest area (61%, 647,600 km^2), followed by the shelf (28%, 304,200 km^2), abyssal plain/deep ocean floor (9%, 100,100 km^2), and rise (1%, 15,800 km^2). Relative to the rest of Australia's EEZ, the NWMR has a significantly larger percentage of slope and far lower percentage of abyssal plain/deep ocean floor. The NWMR contains approximately 16% of area of slope in the entire EEZ (Fig. 4.1; Table 4.1).

Of the 21 geomorphic features defined on the Australian margin, 19 are represented in the NWMR. Seamounts/guyots and escarpments are not represented (Fig. 4.2; Table 4.1).

Large areas of the shelf, slope and abyssal plain/deep ocean floor in the NWMR have not yet been identified in geomorphic features. These areas comprise 35% of the total NWMR area (shelf = 16%, slope = 16%, and abyssal plain/deep ocean floor = 3%). Geomorphic features covering significant areas of these provinces include terraces and plateaus on the shelf and slope which comprise 321,100 km^2 (30% of the area of these provinces in the NWMR). Knoll/abyssal hills/mountains/peaks and ridges are the only geomorphic features identified on the abyssal plain/deep ocean floor and cover 7,800 km^2 (<1%). No geomorphic features have been identified on the rise.

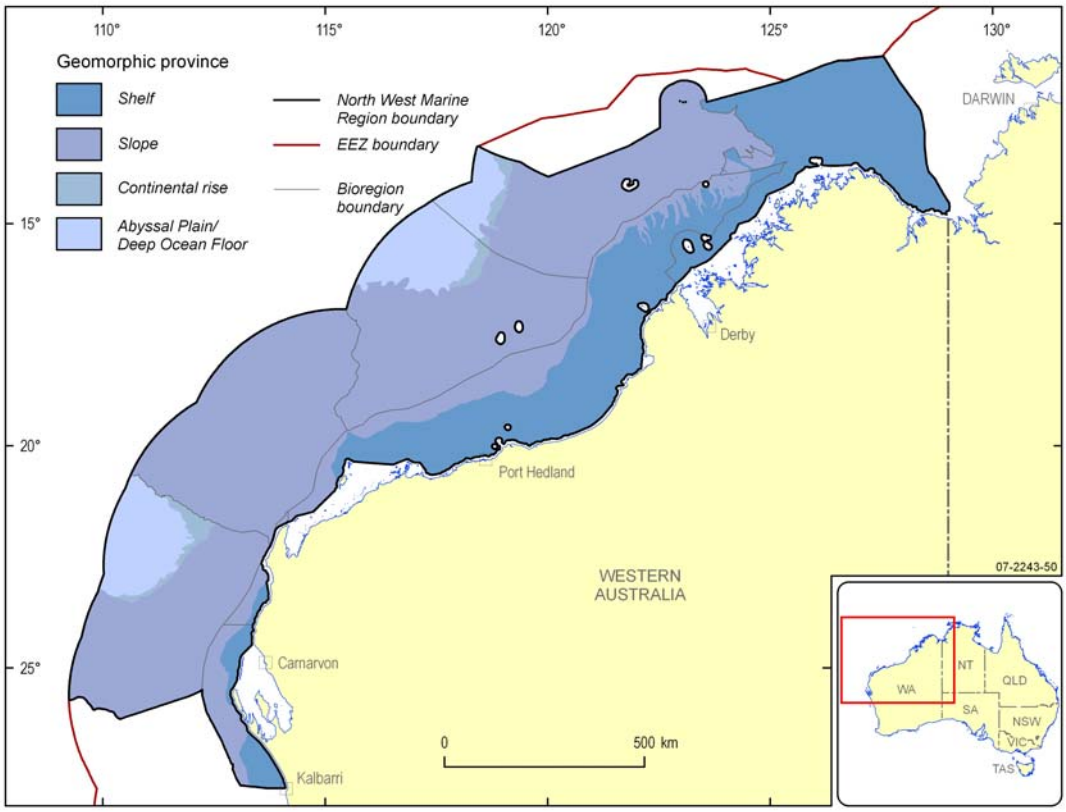
There are no geomorphic feature types that are unique to the NWMR, but some features that occur in the NWMR are rare elsewhere in the EEZ or the latitudes or water depths at which they occur in the NWMR. The NWMR contains a large proportion of the total area of several geomorphic features over the EEZ: Relative to the entire EEZ, the NWMR is particularly rich in banks/shoals, deeps/holes/valleys and terraces. Banks/shoals in the NWMR cover 29,100 km^2 or 58% of the total area of banks/shoals in the EEZ, followed by deeps/holes/valleys (93,300 km^2; 56%); and terraces (227,000 km^2; 39%) (Fig. 4.2; Table 4.1).

Table 4.1. Statistics of geomorphic provinces and features of the NWMR.

Feature	Area in NWMR	% Total NWMR Area	% EEZ Area	% Total area of feature in EEZ located in NWMR	Water Depth Range in NWMR (m)
Geomorphic Provinces					
Shelf	304,170	28.49	21.76	15.50	0 - 330
Slope	647,650	60.66	44.42	16.17	34 – 5,705
Rise	15,845	1.48	1.13	15.50	4,035 – 5,695
AP/DOF*	100,065	9.37	31.96	3.47	3,289 – 5,975
Geomorphic Features					

Shelf	134,115	12.56	13.79	10.78	0 - 200
Slope	310,580	29.09	15.23	22.61	21 – 5,700
Continental Rise	15,845	1.48	1.06	16.54	4,035 – 5,695
Abyssal Plain	98,720	9.25	27.34	4.00	3,375 – 5,975
Bank/Shoals	29,065	2.72	0.56	57.54	4 - 165
Deep/Hole/Valley	93,290	8.74	1.83	56.49	15 – 5,270
Trench/Trough	10,120	0.95	1.93	5.82	570 – 1,285
Basin	19,740	1.85	7.36	2.97	25 - 160
Reef	2,090	0.20	0.52	4.49	35 – 1,330
Canyon	10,790	1.01	1.18	10.10	95 – 5,705
Knoll/Abyssal Hils/Mountains/Peak	2,000	0.19	1.32	1.69	1,700 – 5,605
Ridge	5,800	0.54	1.25	5.20	115 – 5,180
Seamount/Guyot	0	0	1.11	0	-^
Pinnacle	680	0.06	0.06	13.24	5 - 295
Plateau	94,115	8.81	16.59	6.29	15 – 4,625
Saddle	7,990	0.75	1.62	5.45	150 – 4,300
Apron/Fan	735	0.07	0.13	6.29	5 - 460
Escarpment	0	0	0.23	0	-^
Sill	3,720	0.35	0.19	21.44	70 - 95
Terrace	226,975	21.26	6.43	39.16	10 – 4,995
Tidal Sandwave/Sand Bank	1,355	0.13	0.27	5.64	0 - 85
TOTAL	*1,067,725*				

* AP/DOF = Abyssal plain/deep ocean floor.
^ cell size too small to calculate bathymetry



a)
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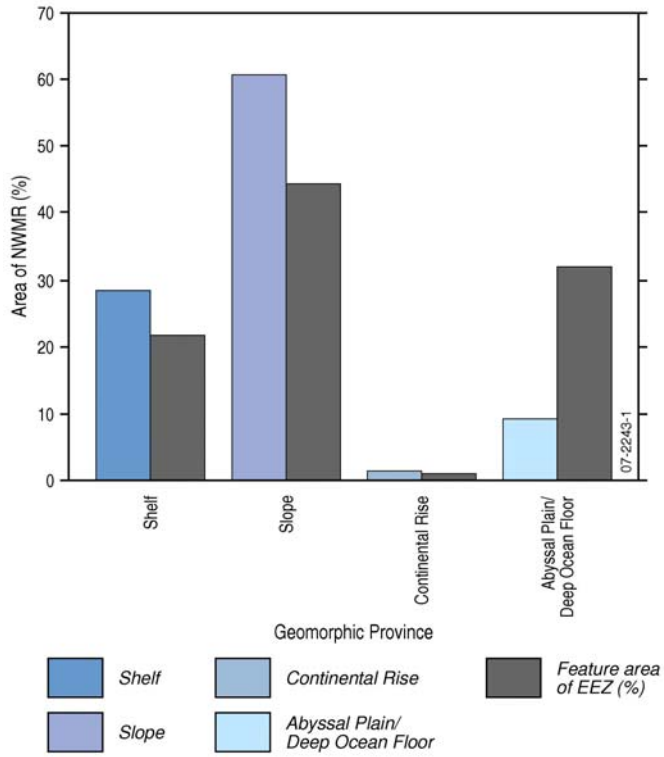
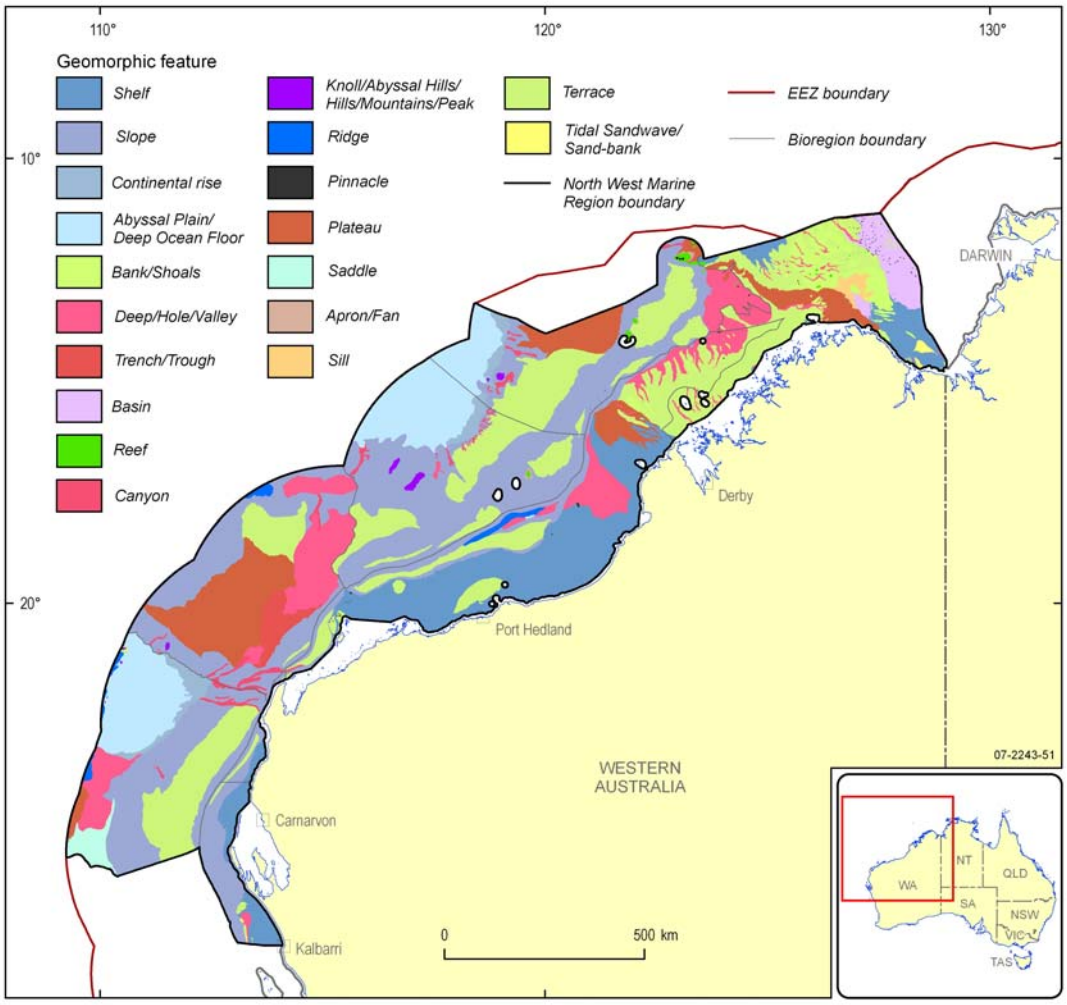


Figure 4.1. a) Geomorphology of the NWMR and b) percentage area of each geomorphic province within the NWMR and EEZ.


110°
120°
130°
10°
20°
Geomorphic feature
Shelf
Slope
Continental rise
Abyssal Plain/ Deep Ocean Floor
Bank/Shoals
Deep/Hole/Valley
Trench/Trough
Basin
Reef
Canyon
Knoll/Abyssal Hills/ Hills/Mountains/Peak
Ridge
Pinnacle
Plateau
Saddle
Apron/Fan
Sill
Terrace
Tidal Sandwave/ Sand-bank
North West Marine Region boundary
EEZ boundary
Bioregion boundary
DARWIN
Derby
Port Hedland
WESTERN AUSTRALIA
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Kalbarri
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VIC
TAS

a)

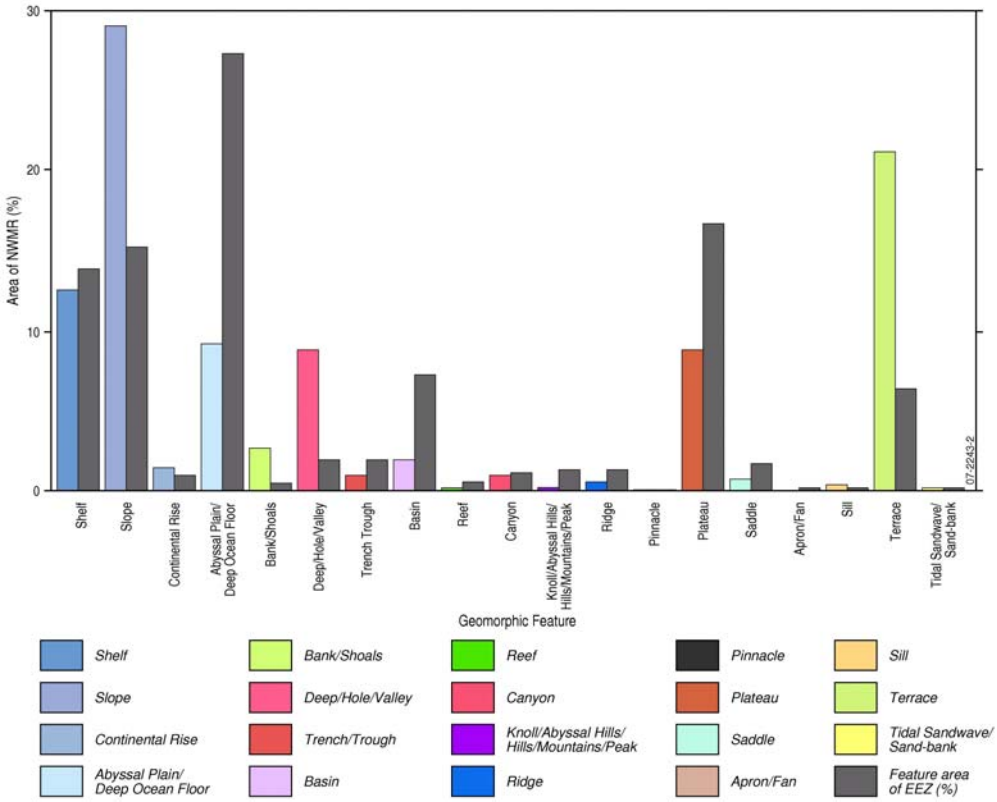


Figure 4.2. a) Geomorphology of the NWMR and b) percentage area of each geomorphic feature within the NWMR and EEZ.

4.1.2. Bathymetry

Water depths in the assessed area of the NWMR range from 0 – 5,980 m (Table 4.1; Figs. 4.3). The NWMR is relatively shallow, with >40% of the total area in water depths of <200 m and >50% in depths of <500 m. This reflects the broad shelf and slope that occurs along much of the northwestern Australian margin. Compared with the entire EEZ, the NWMR contains a relatively small area of deep water (>4,000 m). Water depths of >4,000 m comprise <15% of the NWMR area, or <5% of the total EEZ area (Fig. 4.3).

Basins, pinnacles and apron/fans in the NWMR have a limited depth range compared to the rest of the Australian margin, occurring only in water depths shallower than 500 m (Table 4.1). Elsewhere in the EEZ, these features occur in water depths from 0 to >5,000 m (Potter et al., 2006).

More than 70% of the total area of knoll/abyssal hills/hills/peaks in the NWMR occur at water depths of >4,000 m. Elsewhere in the EEZ, these features are most common at water depths of <1,500 m (see, Potter et al., 2006). Knoll/abyssal hills/hills/peaks in the NWMR comprise >70% of the total area of this feature across the EEZ in water depths of >4,000 m.

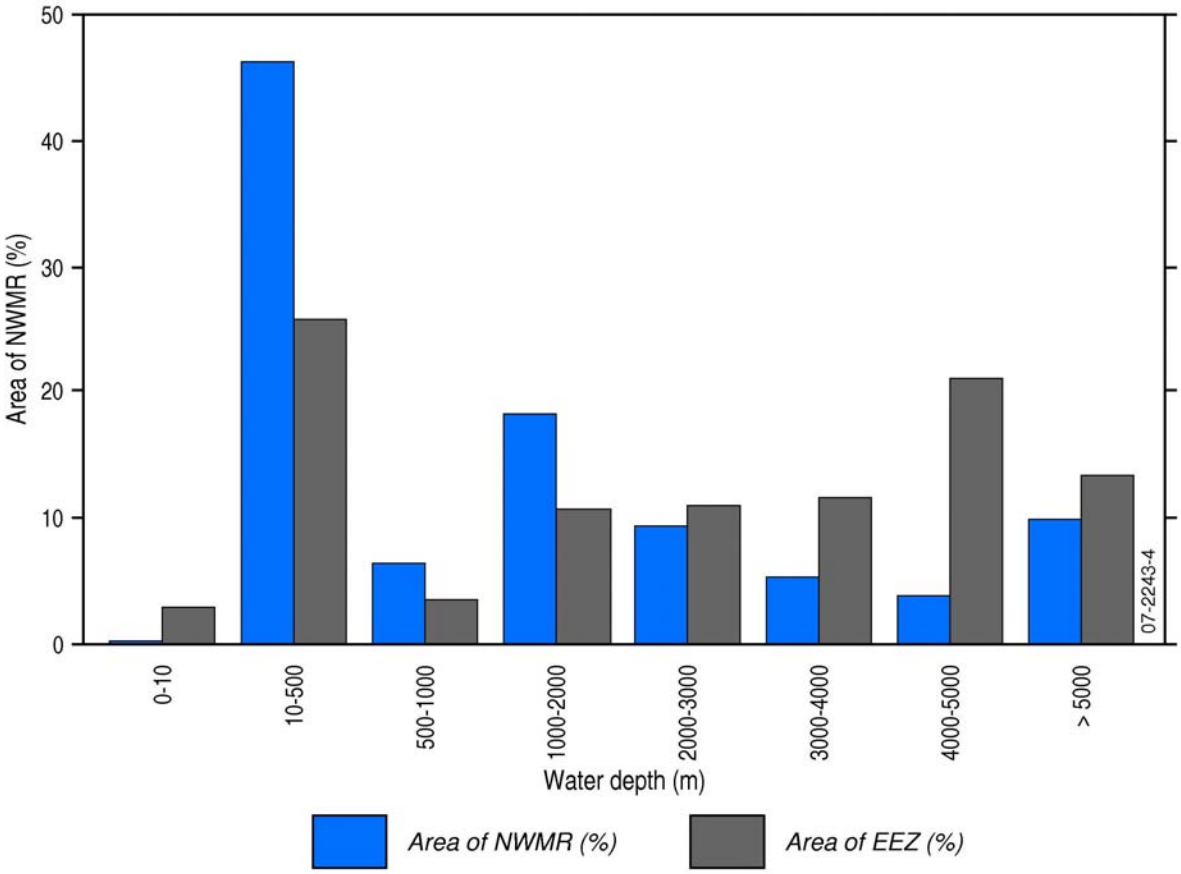


Figure 4.3. Distribution of water depths for the NWMR (grey bars) and EEZ (grey bars) expressed as percentages.

4.1.3. Sediment Data Coverage in the NWMR

4.1.3.1 Quantitative Textural and Compositional Data

Sample density varies significantly across the NWMR (Fig. 4.4 & Fig. 4.5). Sample density exceeds ten samples per 1,000 km² for more 35% of the total area of the NWMR and exceeds 50 samples per 1,000 km² for >3%. Sample density does not attain one sample per 1,000 km² for approximately 20% of the NWMR area (Fig. 4.5). Samples are clustered as a result of collection on surveys of local areas or targeting specific seabed features. In general, sample coverage is most dense on the mid to outer shelf and the upper slope (Fig. 4.6). Samples are relatively sparse in deep water areas and on much of the inner shelf (Fig. 4.6 & 4.7).

A total of 449 samples (46% of samples in the NWMR) are from the shelf, resulting in an average sample density of approximately 1.5 samples per 1,000 km² (Fig. 4.7; Table 4.2). A total of 508 (52%) samples are from the slope, resulting in an average density of 0.8 samples per 1,000 km². Only 11 (<2%) samples occur on the rise and abyssal plain/deep ocean floor; however, as these provinces form a relatively small area of the NWMR (~115,900 km², <11%), this gives an average density of 0.1 samples per 1,000 km² (Fig. 4.7). Samples achieve adequate coverage to assess the sedimentology in 11 of the 19 geomorphic features present in the NWMR. No samples were collected from saddles. Less than three samples were collected from the rise, knoll/abyssal hills, aprons/fans, sills and tidal sand wave/sandbanks. Together, these features cover approximately 23,660 km² (<2%) of the NWMR (Table 4.1).

Average sample densities exceed 0.8 samples per 1,000 km² for all features, covering >100,000 km² or 10% of the NWMR. Of those features containing adequate samples for analysis, highest sample densities were achieved for pinnacles and ridges (~3 samples per 1,000 km²) and deeps/holes/valleys and aprons/fans (~1.4 samples per 1,000 km²). Low numbers of samples and/or spatial clustering of samples on some features mean that assays may not be representative of seabed properties for the entire feature across the NWMR. Low numbers of samples may significantly affect results for trench/trough, reefs, canyons and pinnacles. A total of eight samples occur on the abyssal plain/deep ocean floor in the NWMR. Clustering may significantly affect results for canyons, ridges, and terraces.

Despite targeted addition of data points, coverage remains poor (<1 sample per 1,000 km²) particularly for some areas of the inner shelf, the abyssal plain/deep ocean floor and rise. Addition of data improved coverage of deeps/holes/valleys and knoll/abyssal hills that occur in water depths >4,000 m (1 sample added to each)but was unable to achieve coverage of ridges, canyons and saddles occurring at these water depths in the NWMR.

It is important to note that average densities and areas given for these will vary depending on the scale (Marine region/province/feature) at which density is being assessed.

Table 4.2. Description of average density of samples per geomorphic province or feature.

PROVINCE/ # Feature	No. sample points	% NWMR Area	Average sample density (samples per 1,000 km²)
Geomorphic Province			
Shelf	449	28.49	1.48
Slope	508	60.66	0.78
Rise	1	1.48	0.06
Abyssal Plain/ Deep Ocean Floor	10 + 18 in deepwater outside EEZ	9.37	0.10
Geomorphic Province			1.70
Shelf (unassigned)	228	12.56	0.79
Slope (unassigned)	244	29.09	0.06
Continental rise (unassigned)	1	1.48	0.08
AP/DOF (unassigned)	8	9.25	1.31
Bank/Shoals	38	2.72	1.40
Deep/Hole/Valley	131	8.74	0.30
Trench/Trough	3	0.95	1.32
Basin	26	1.85	1.43
Reef	3	0.20	0.37
Canyon	4	1.01	1.00
Knoll/Abyssal Hills/Mountains/Peak	2	0.19	3.10
Ridge	18	0.54	2.95
Pinnacle	2	0.06	0.46
Plateau	43	8.81	0.00
Apron/Fan	0	0.75	1.36

Sill	1	0.07	0.27
Terrace	1	0.35	0.93
Tidal Sandwave/Sand bank	211	21.26	2.95

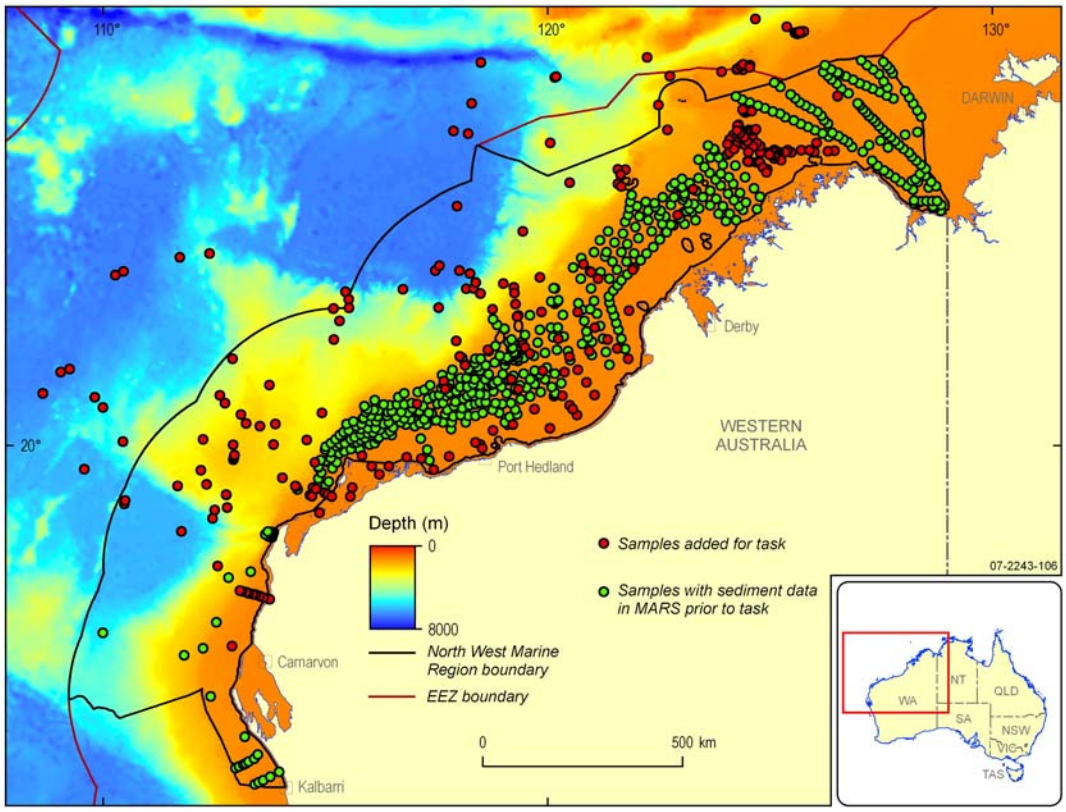
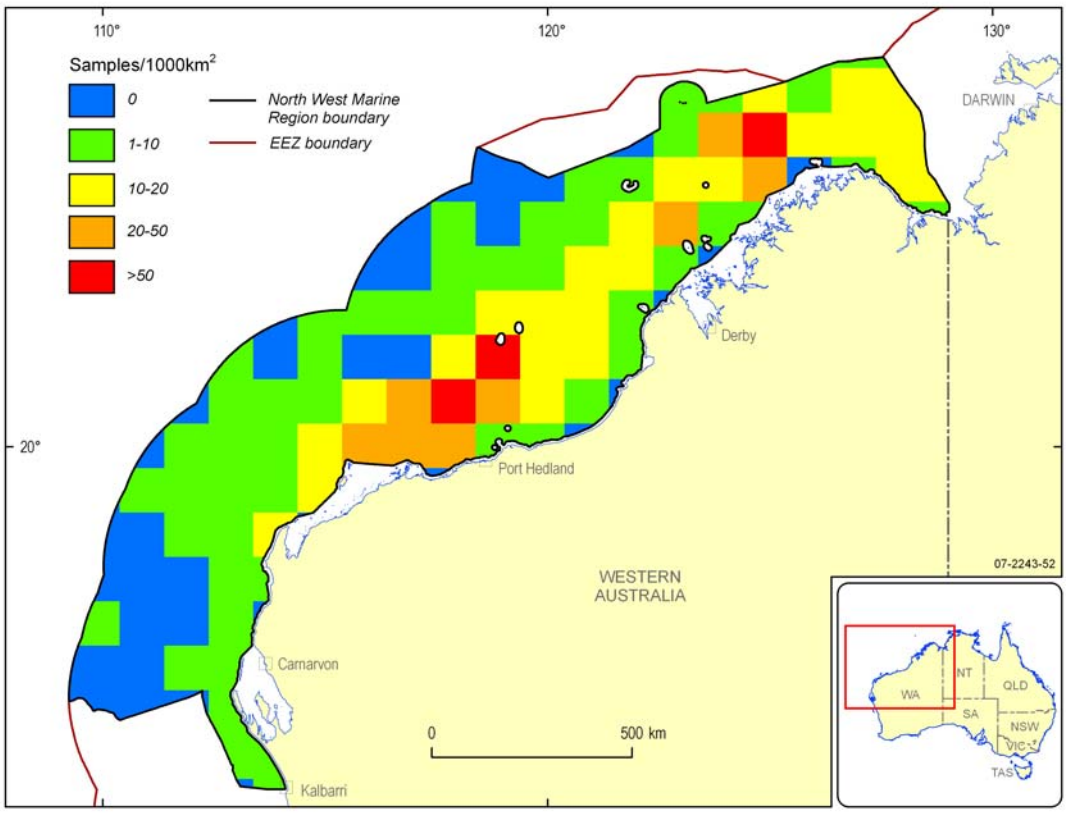


Figure 4.4. Location of all quantitative textural and compositional sample points for the NWMR in relation to bathymetry.



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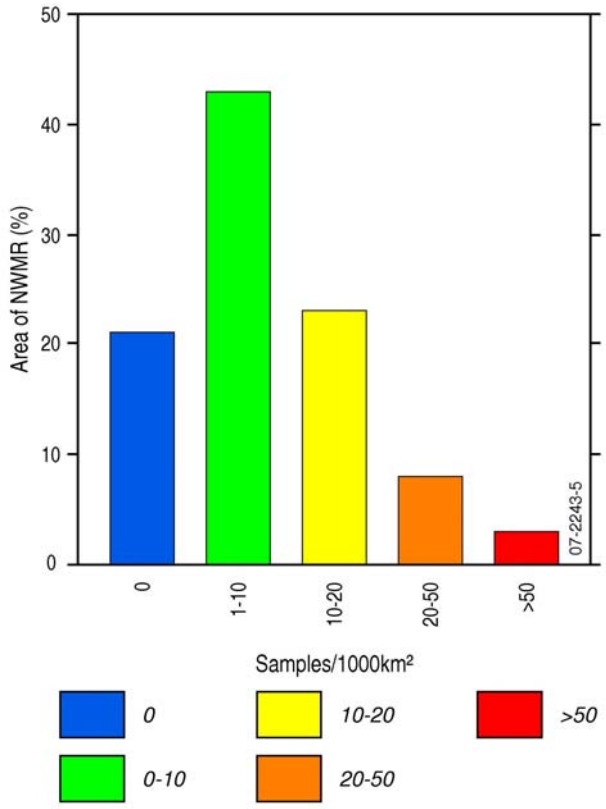


Figure 4.5. a) Sample density distribution across the NWMR, and b) Frequency distribution of sample density.

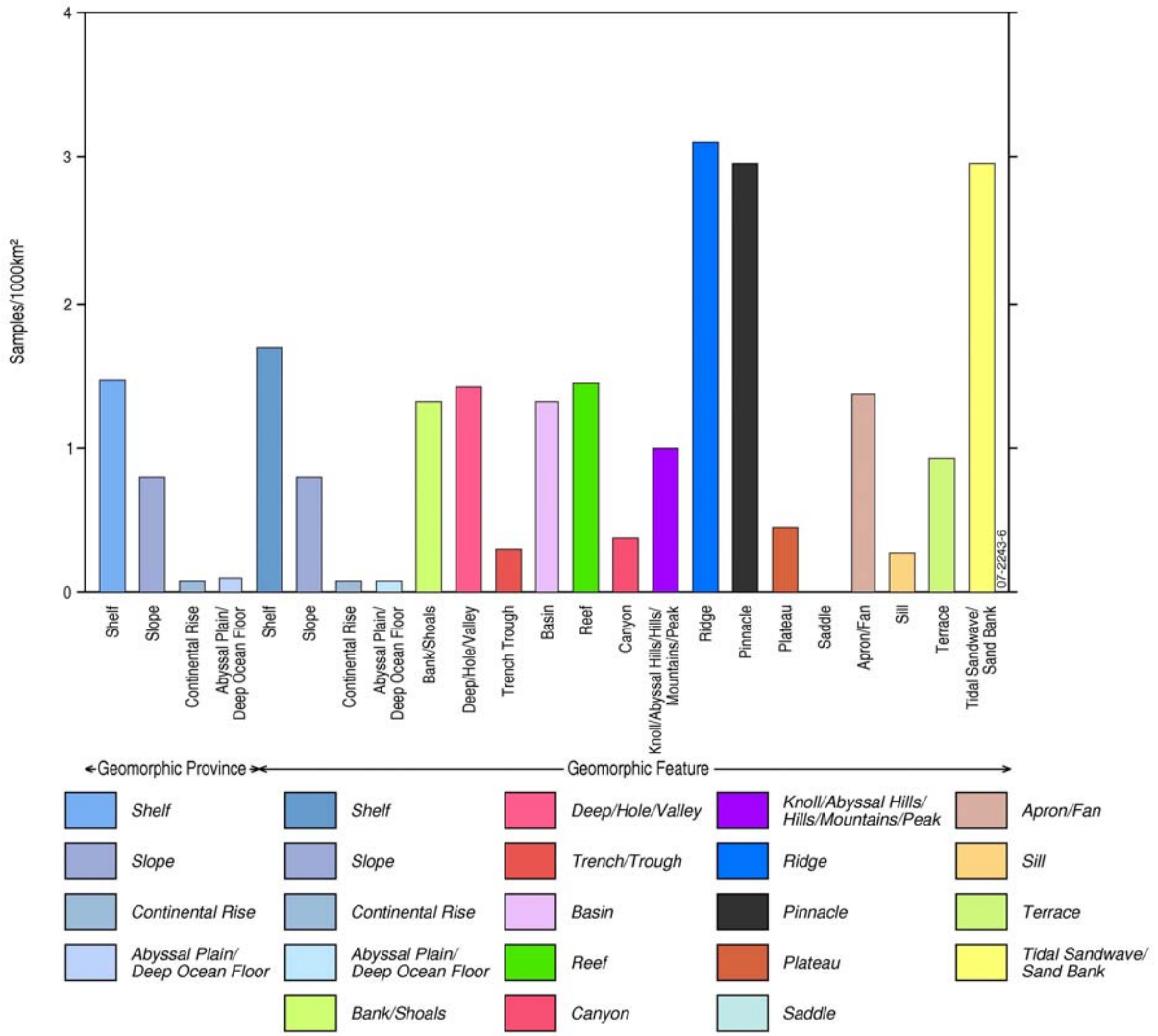
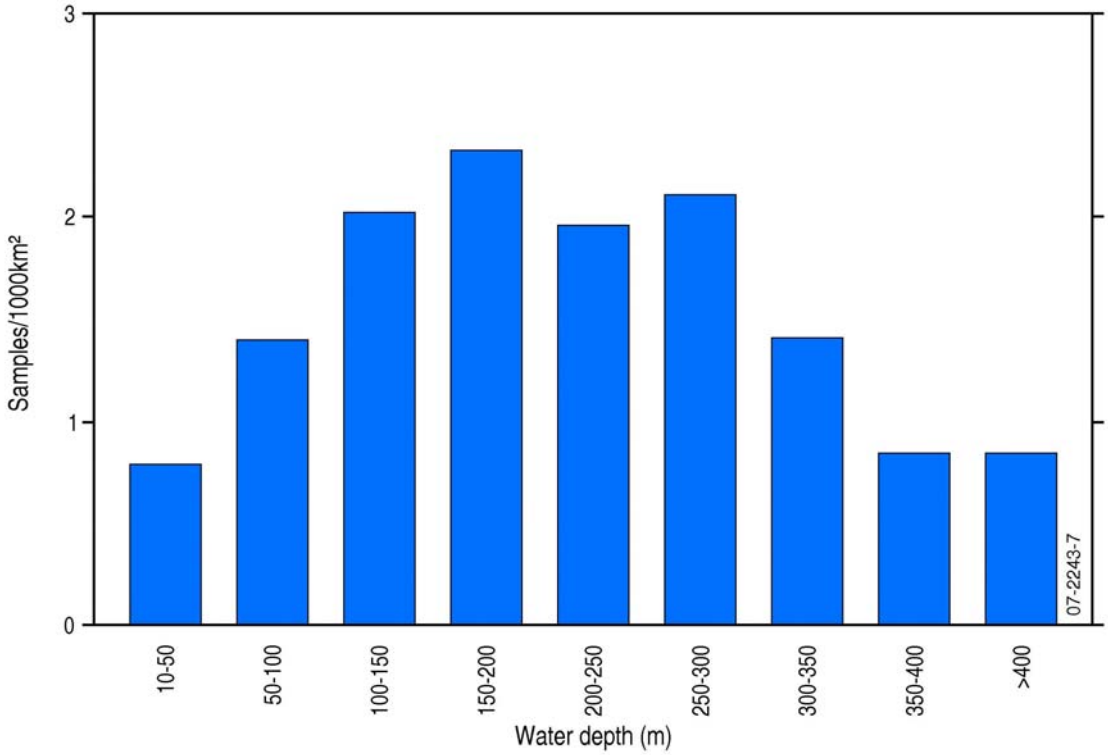


Figure 4.6. Sample density of geomorphic provinces and features in the NWMR (y axis shows average density measured as samples per 1,000 km²).

a)



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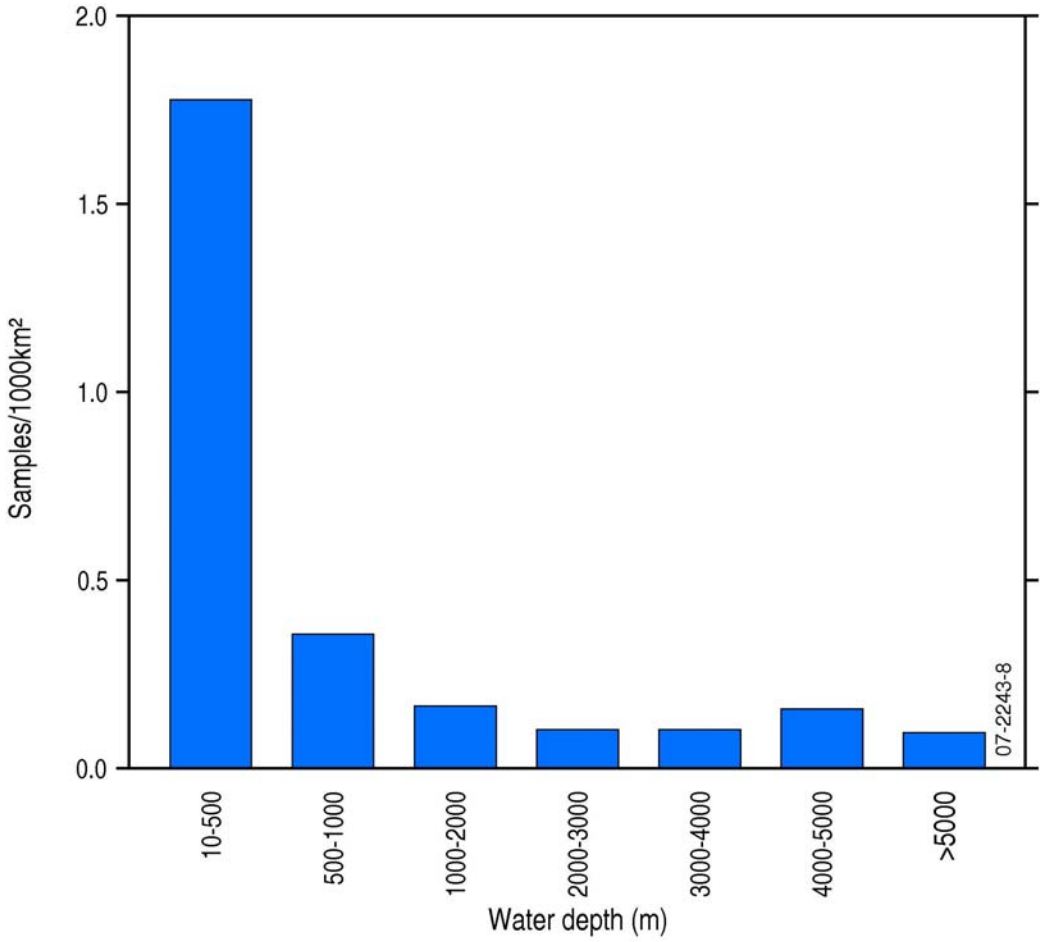


Figure 4.7. Sample density for water depths for a) depths <500 m in the NWMR, and b) for all provinces in the NWMR (y axis shows average density measured as samples per 1,000 km²).

4.1.4. Quantitative regional sediment distribution in the NWMR

4.1.4.1. Overview of Distribution and Properties

Sample assays indicate that the seabed in the NWMR is characterised by a range of sediment types (Fig. 4.8). Sand is the dominant size fraction with approximately 627 samples (65%) containing >50% sand. A total of 43 samples (4%) contained <10% sand (Fig. 4.11b). Sand is the dominant size fraction in samples located on the shelf and upper slope except in the Bonaparte Depression and on the Londonderry Rise where mud comprises >50% of sediment at approximately 80 (30%) sites sampled (Figs. 4.10 & 4.11).

A total of 222 samples (23%) contained >50% mud and 384 (40%) samples contained <10% mud (Fig. 4.10b). Mud is the dominant size fraction on the slope, rise and abyssal plain/deep ocean floor (Figs. 4.10a & 4.14). Samples containing <10% mud generally occur on the shelf and upper slope.

Gravel is detected in 640 (66%) samples but is the dominant size fraction in only 47 (<1%) samples. Gravel forms a minor component (<10%) in approximately 617 samples (64%) (Fig. 4.12b). Gravel occurs most frequently on the shelf and upper slope and is generally absent from deep water areas (Fig. 4.12a, 4.14). The abundance and distribution of sediment containing gravel is likely to be underrepresented in the data due to sparse sample coverage of areas of the NWMR closest to the coast.

Carbonate is the dominant constituent of the sediment with 568 (69%) samples composed of >80% carbonate (Figs. 4.9 & 4.13b). Less than 28 samples (<4%) contain <10% carbonate. Carbonate content generally decreases with increasing water depth, with more than 50% of samples on the shelf and upper slope containing >90% carbonate (Fig. 4.13a). Carbonate contents on the lower slope generally vary between 20 and 90%. Exceptions occur in the Bonaparte Depression and on the shelf around Shark Bay. In the Bonaparte Depression, shelf sediment contains <80% carbonate and frequently <20% (Fig. 4.13a).

All size fractions are dominated by carbonate grains (Fig. 4.9). Carbonate mud contents attain >50% for 231 (28%) samples. Carbonate mud content generally shows variation over large distances, with assays of similar contents clustered even at a regional scale. As >1 g of mud is required to perform this analysis, assays are mainly from samples off the shelf and may not to be representative of carbonate contents of mud across the entire planning region.

Carbonate sand is the dominant constituent of sediment in the NWMR with contents attaining >50% in 408 (50%) samples. The carbonate content of sand varies spatially, although lower concentrations are generally more frequently observed in close proximity to the coast. Exceptions to this trend occur in the Bonaparte Depression and on the Londonderry Rise where carbonate sand contents are <60% and frequently <20%. Carbonate contents of sand in this region are generally <60% and frequently <20%.

Gravel is entirely composed of carbonate grains in 270 (33%) samples. Carbonate is exceeded by other constituents in only three (<1%) samples. These occur on the slope and represent the deepest-water occurrences of gravel detected in the NWMR. It is not possible to observe spatial

trends in carbonate contents of gravel as volumes of gravel necessary to complete this analysis were only collected from the shelf and upper slope.

Sediment assays were interpolated using the methods described in Chapter 2 to give an estimate of regional distribution of sediment properties in the NWMR. Interpolated grainsize data achieves coverage of approximately 735,500 km (69%) of the total NWMR. Uneven distribution of data points in the region means that interpolated sediment data covers 335,200 (85%) of the shelf, 707,550 km² (62%) of the slope and 119,500 km² (32%) of the rise/ abyssal plain/deep ocean floor. Interpolated bulk carbonate data and folk classification cover similar areas of each province.

The interpolated maps give an interpretation of possible regional distribution of sediment properties (Fig. 4.14). Areas with the highest sand (40-100% sand) and lowest mud (<20% mud) content are located on the mid to upper shelf (Figs 4.10a & 4.11a). Mud content shows a significant increase with water depth, and the highest contents are located within the lower slope, abyssal plain/deep ocean floor, and to the north of the Bonaparte Archipelago. The NWMR is predominantly composed of sediment with a low gravel content (<20%) (Figs. 4.12a & 4.12b).

The highest calcium carbonate contents occur in sediment located within the shallow reaches of Shark Bay and along the Rowley Shelf (Fig. 4.13a). Sediment in the Joseph Bonaparte Gulf is characterised by frequently low carbonate contents. Carbonate content generally decreases with water depth, and the lowest values are found on the lower slope and abyssal plain/deep ocean floor.

Areas of highest gravel composition are found within the Joseph Bonaparte Gulf and offshore of Broome within the northern extent of the Northwest Shelf Province (Fig 4.12a & 4.14). From the Folk Classification (Fig 4.15a), gravely sand (gS) with smaller quantities of sandy gravel (sG) dominate the shelf area, and muddy sand (mS) and gravely muddy sand ((g)mS) dominate the lower slope (Fig 4.15a). The distribution of muddy sand (mS), mud (M), and sandy mud (sM) increases with water depth, and these sediment types are most common with the abyssal plain/deep ocean floor.

The textural composition of seabed sediment grades from sand-dominated to mud-dominated with increasing water depth. A notable change in the sedimentology occurs offshore of the Joseph Bonaparte Gulf towards the extent of the Timor Sea. In this region sediment show a decrease in calcium carbonate composition and an increase in mud content. This change is best observed in the Folk Classification where an increase in the deposition of gravelly muddy sand (gmS) is observed (Fig 4.15a).

It should be noted that interpolated sediment maps and graphs showing sediment composition include only sample points with weight % data. Due to low sample volumes or different analysis methods in the past, mean grainsize is the only information available for many samples. For this reason, sample numbers stated in the text may differ from numbers of points displayed on maps and graphs.

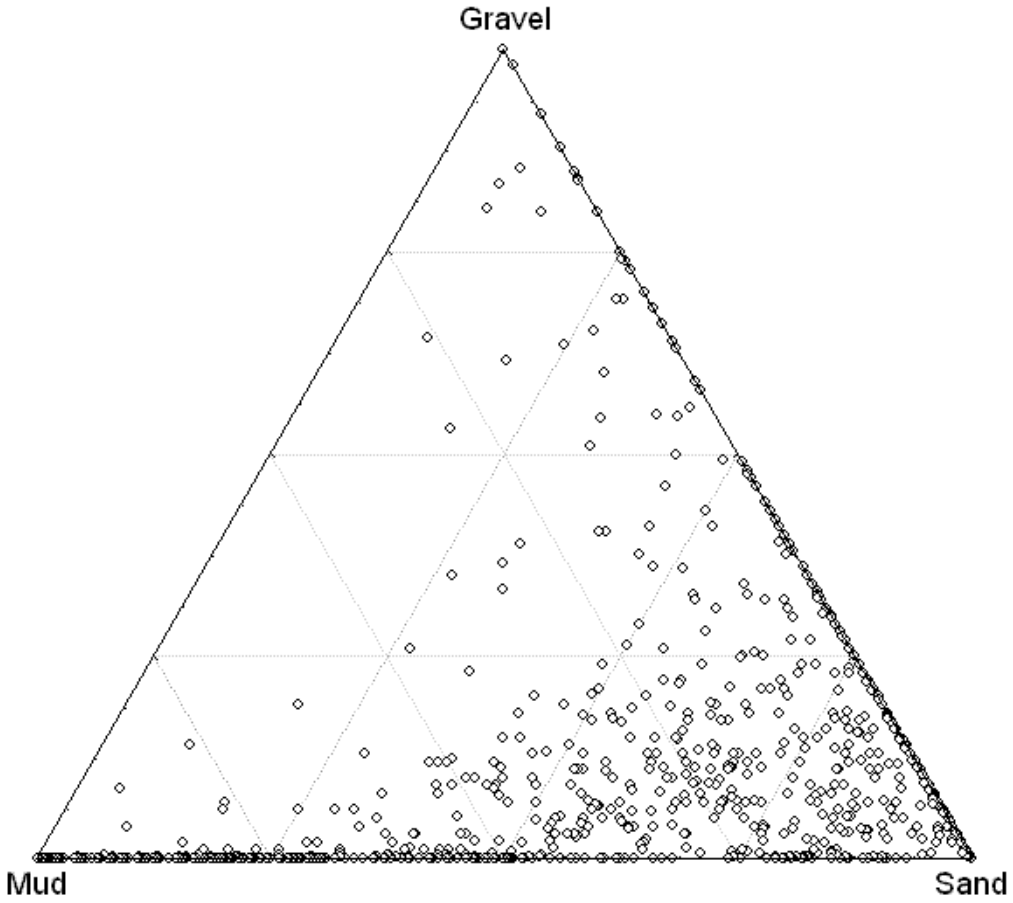
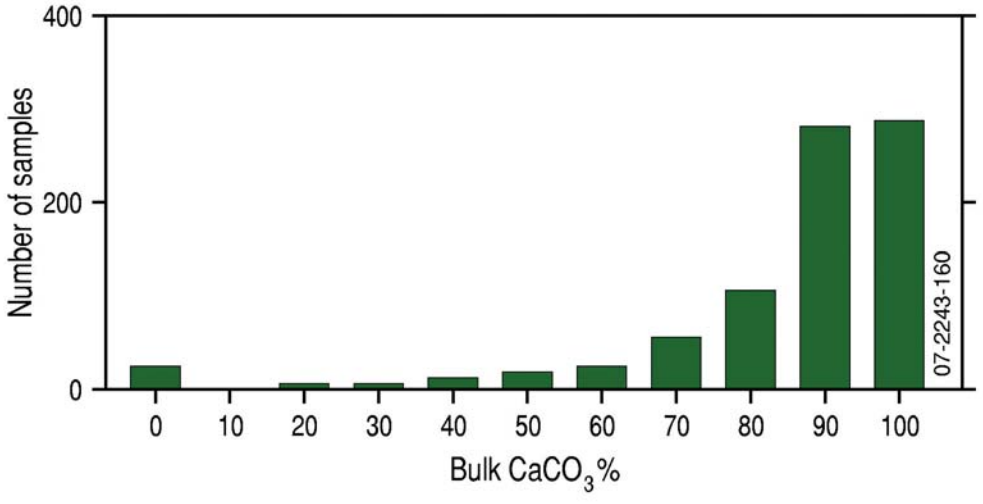


Figure 4.8. Textural composition (mud:sand:gravel ratio) of individual sediment samples within the NWMR.

a)



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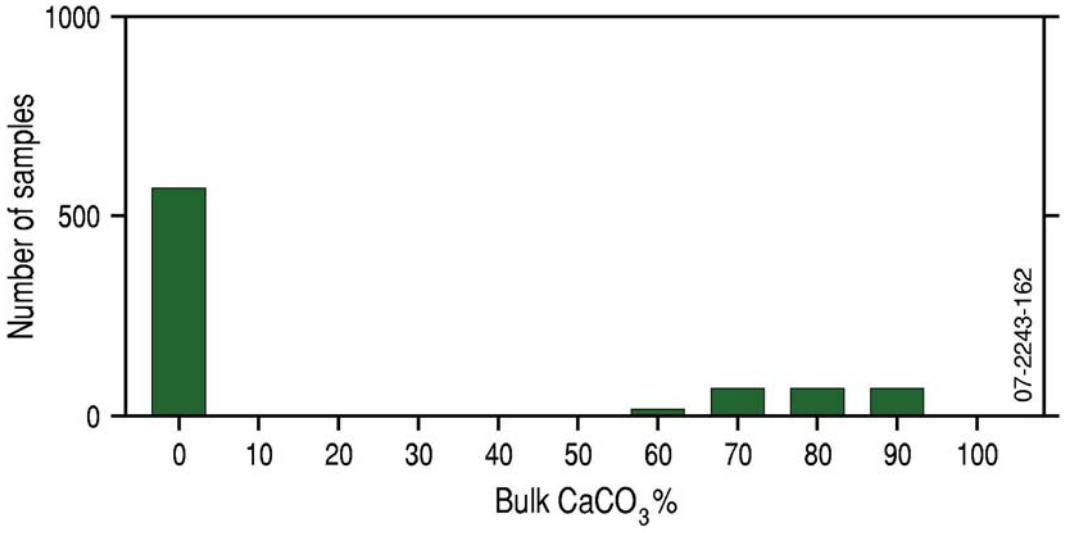

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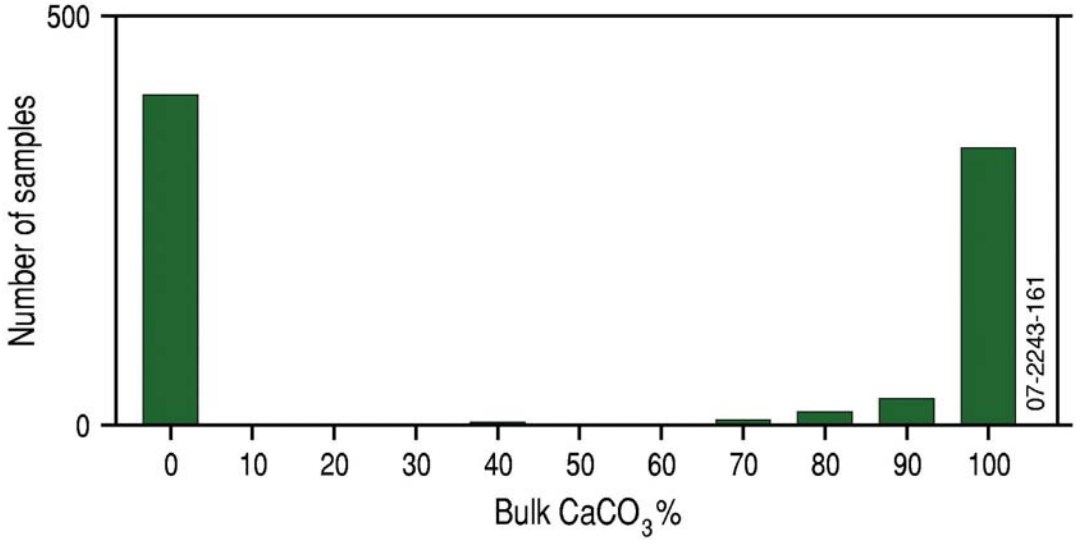

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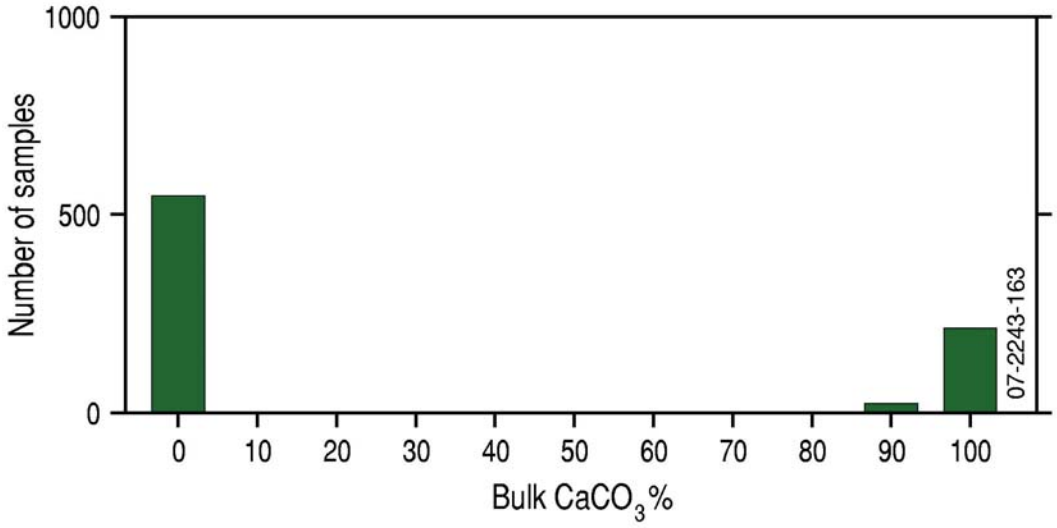
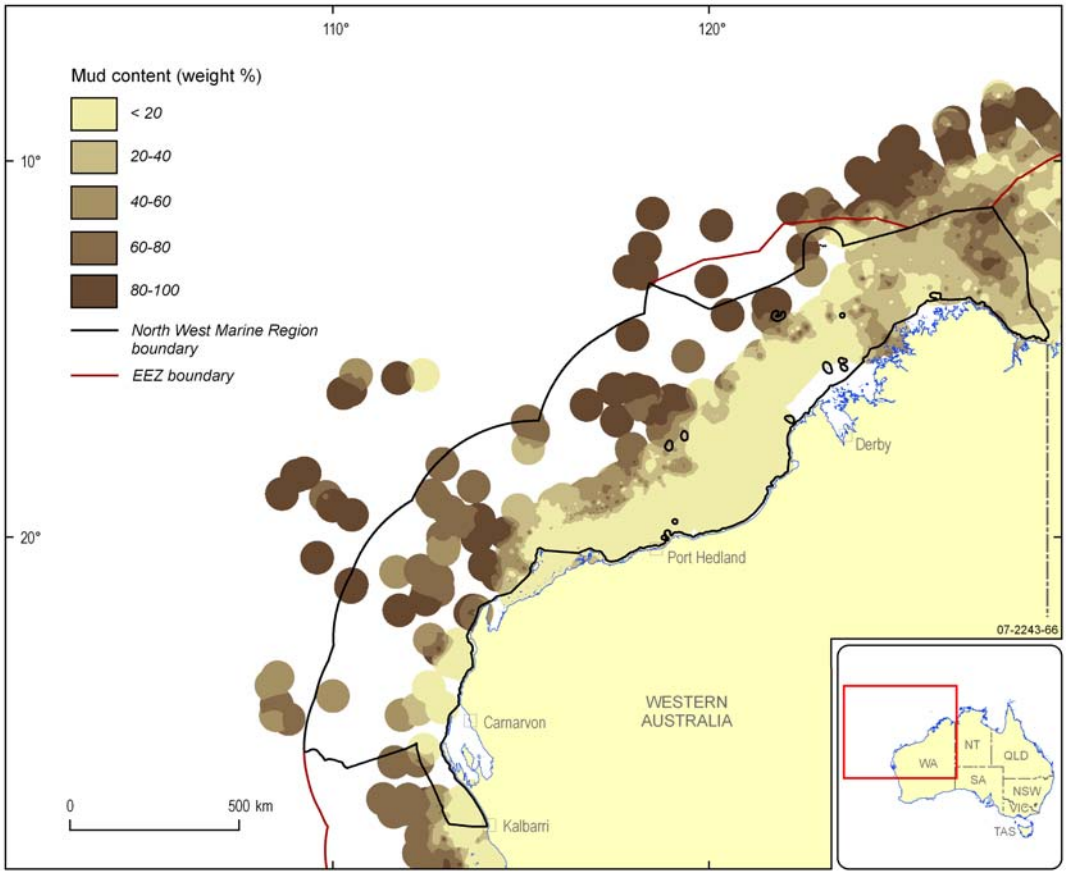


Figure 4.9. a) the bulk carbonate content, and carbonate content of b) mud, c) sand, d)gravel (d) sediments in the NWMR.



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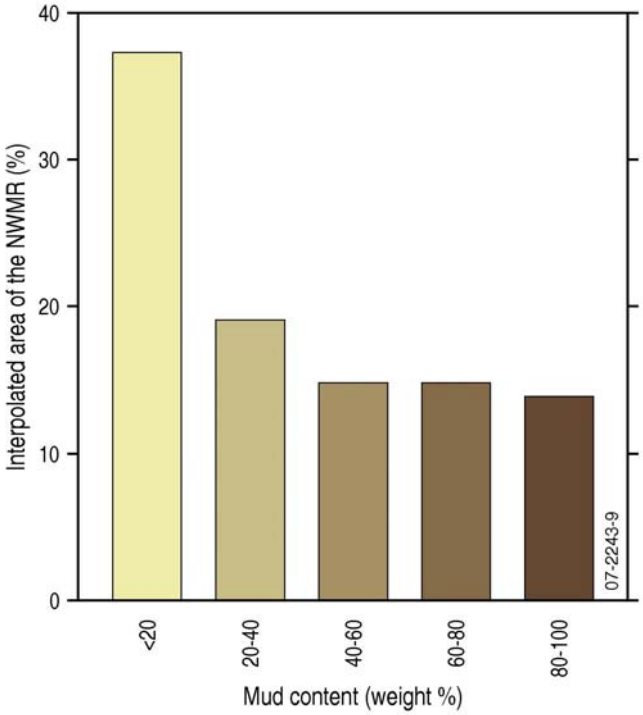
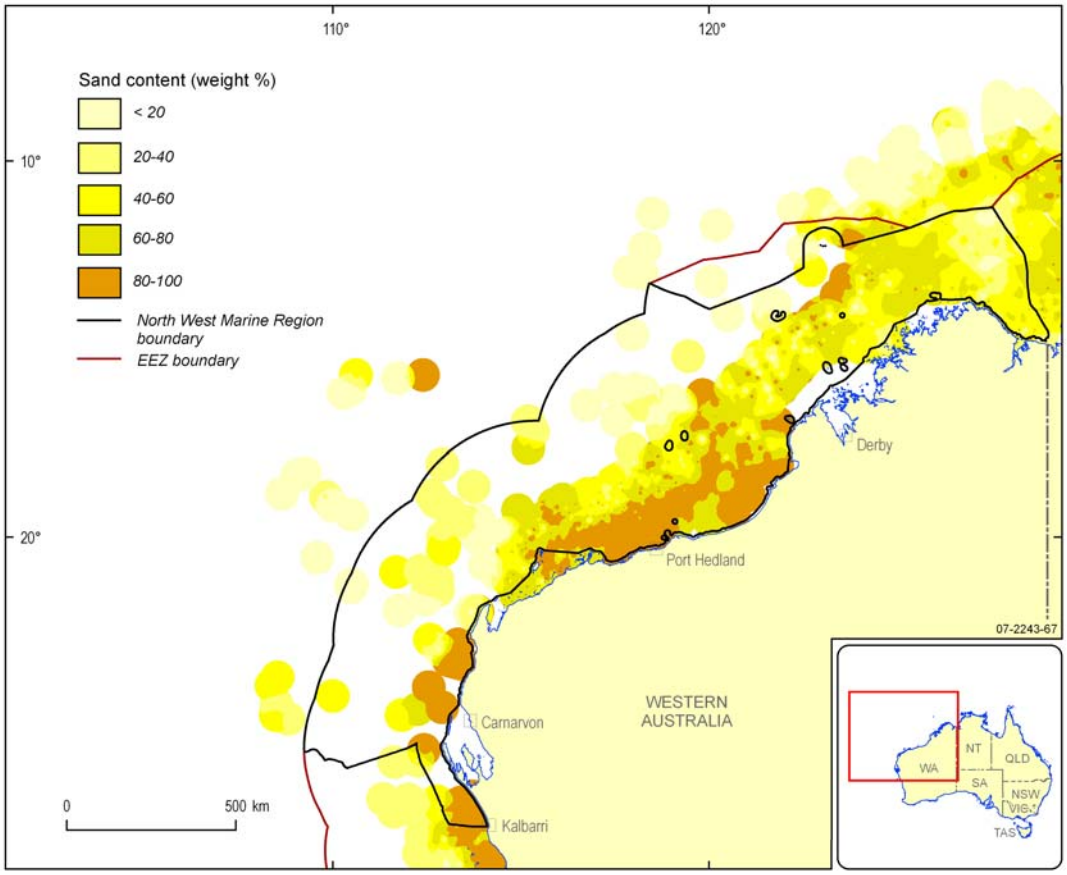


Figure 4.10. a) Mud distribution in the NWMR and b) the area covered by each mud class expressed as % of the interpolated area of the NWMR.



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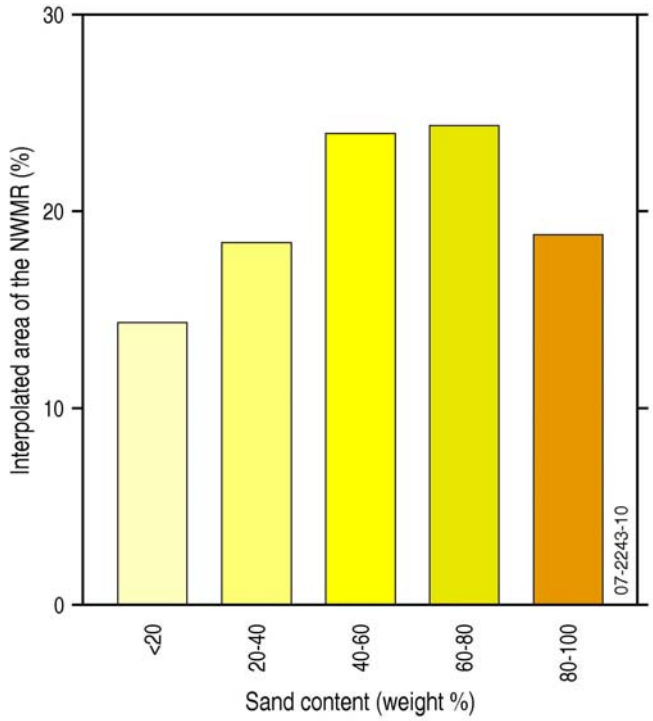
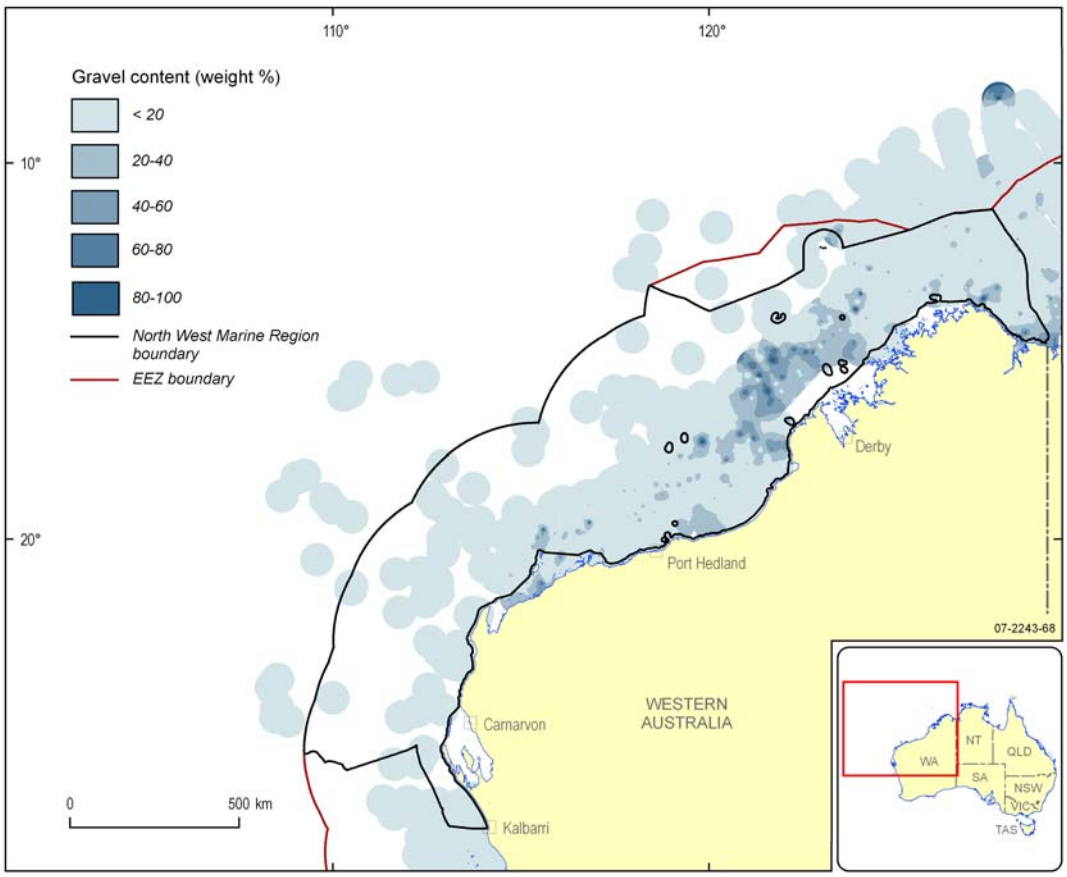


Figure 4.11. a) Sand distribution in the NWMR and b) the area covered by each sand class expressed as % of the interpolated area of the NWMR.



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b)

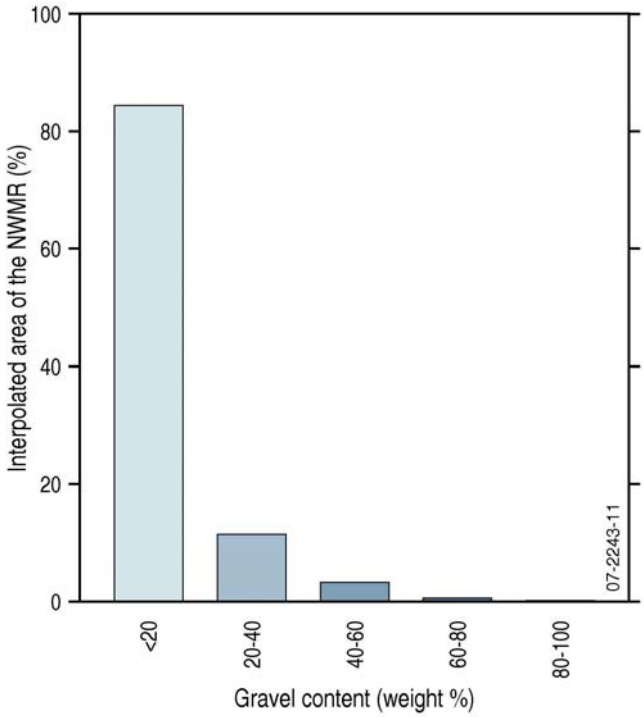
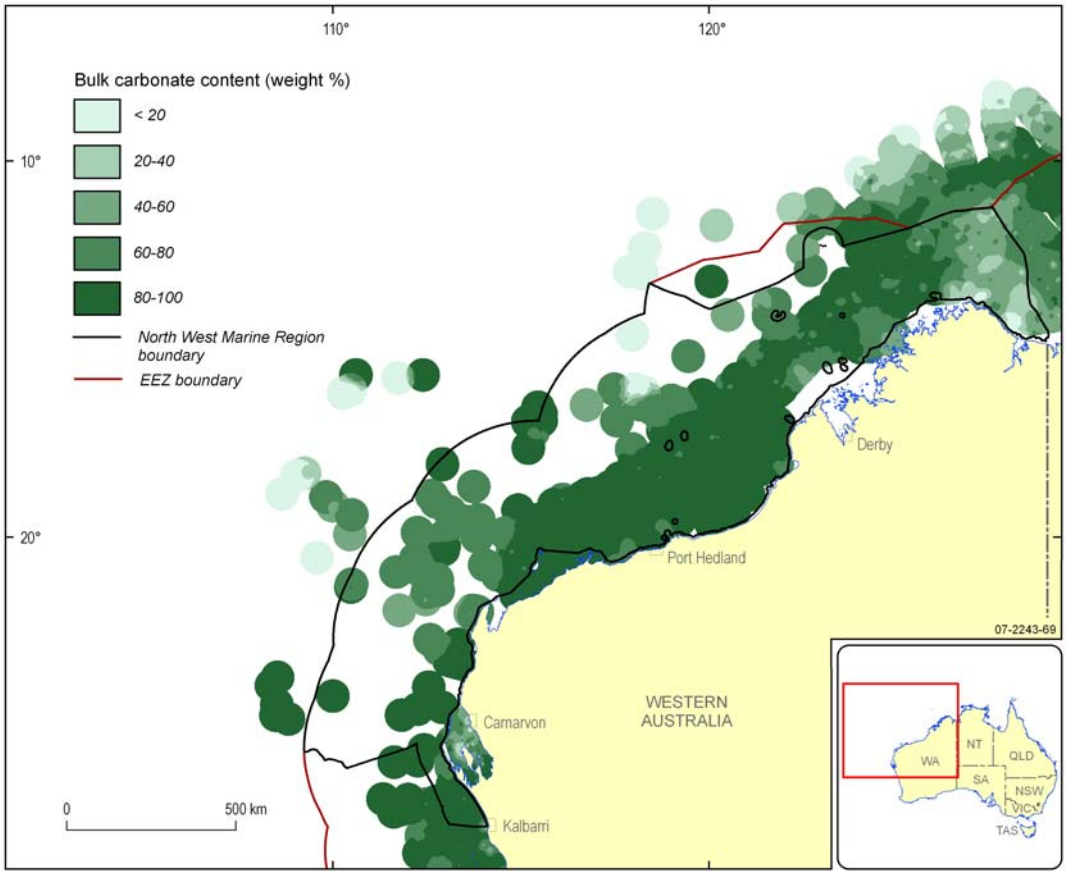


Figure 4.12. a) Gravel distribution in the NWMR and b) the area covered by each gravel class expressed as % of the interpolated area of the NWMR.



a)

b)

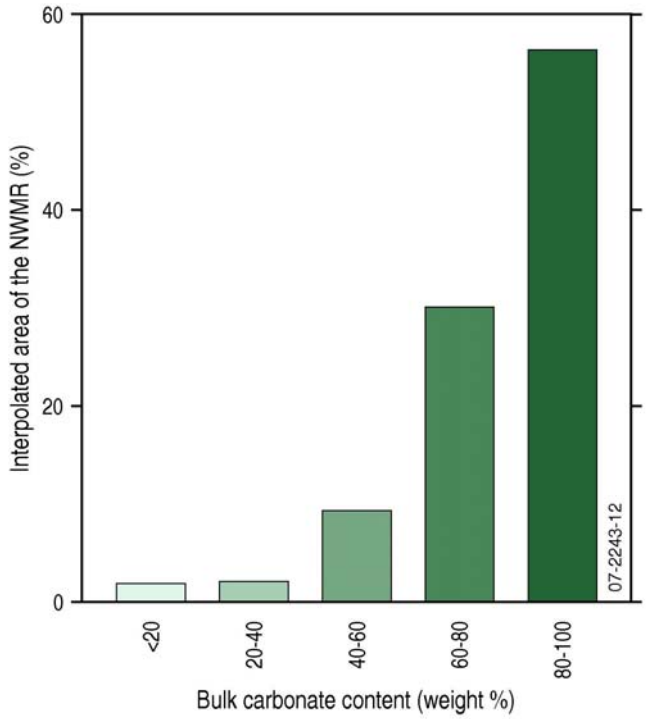


Figure 4.13. a) Carbonate content distribution in the NWMR and b) the area covered by each carbonate content class expressed as % of the interpolated area of the NWMR.

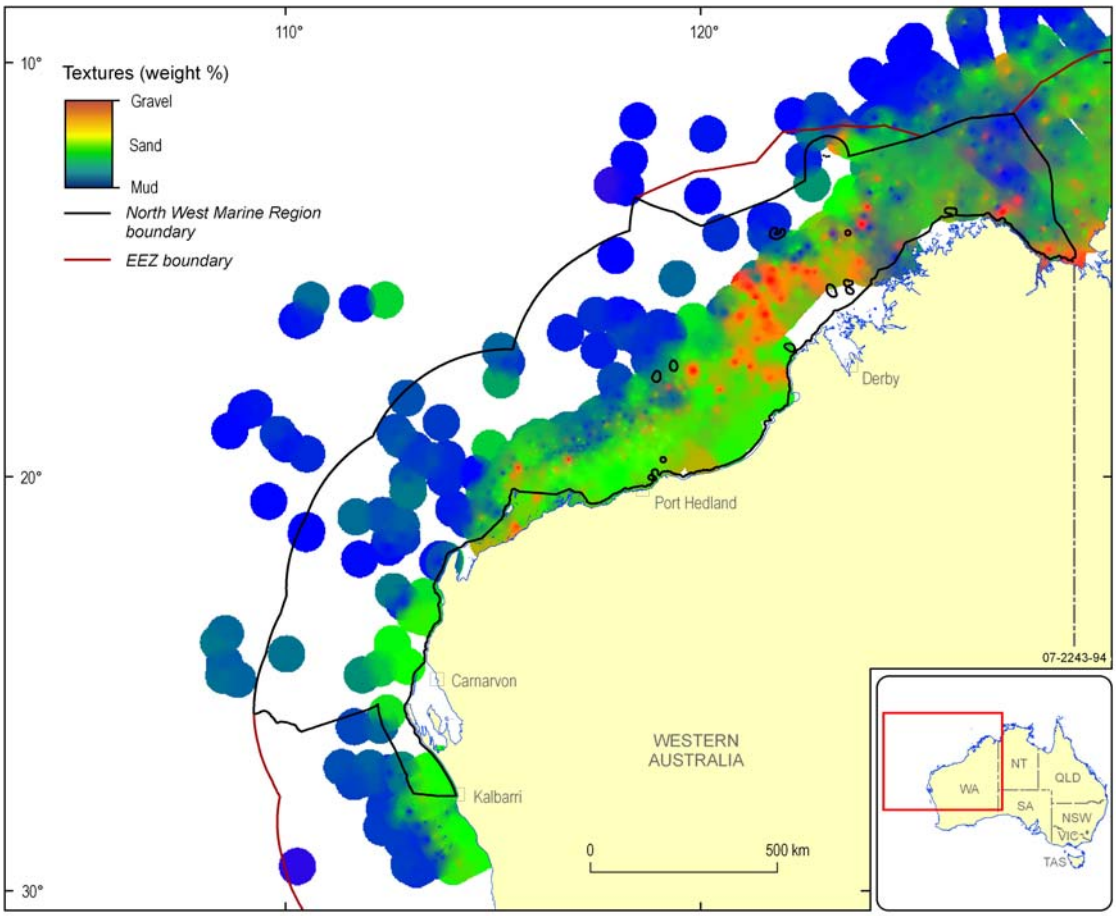
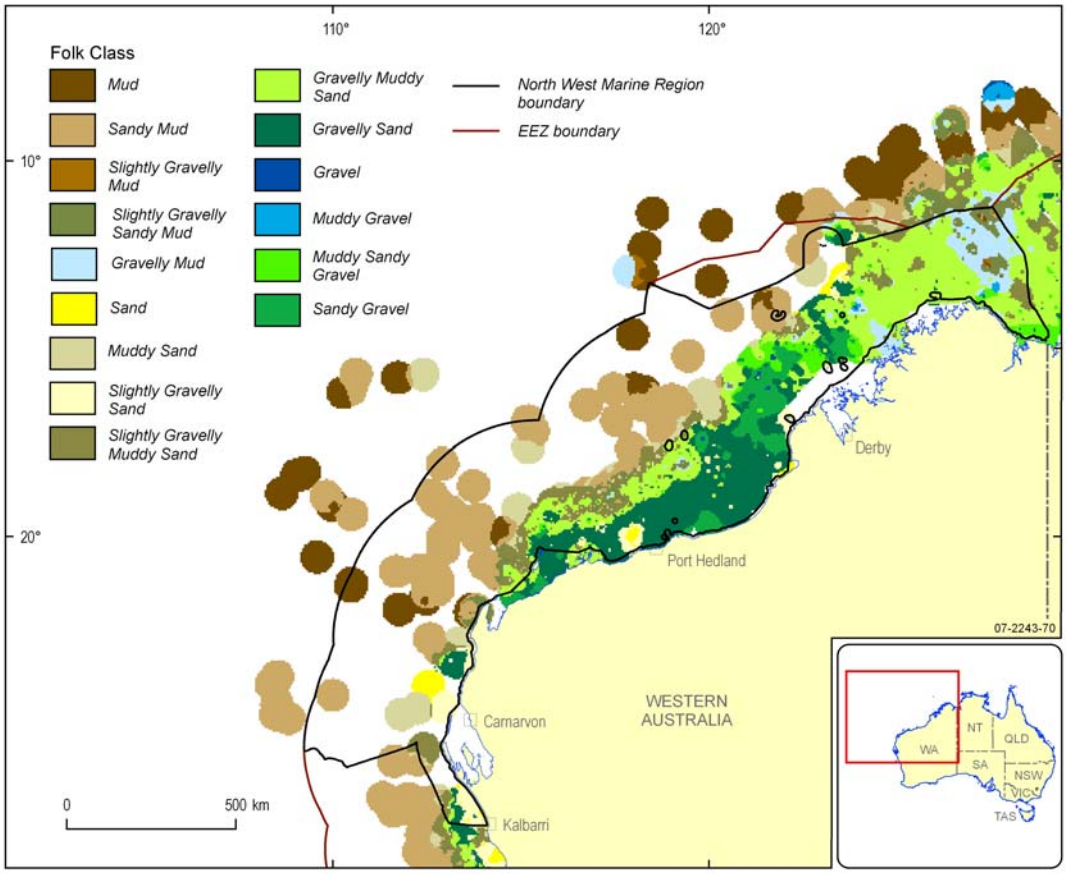


Figure 4.14. Interpolated data for gravel, sand and mud% displayed as an RGB image.

a)



b)

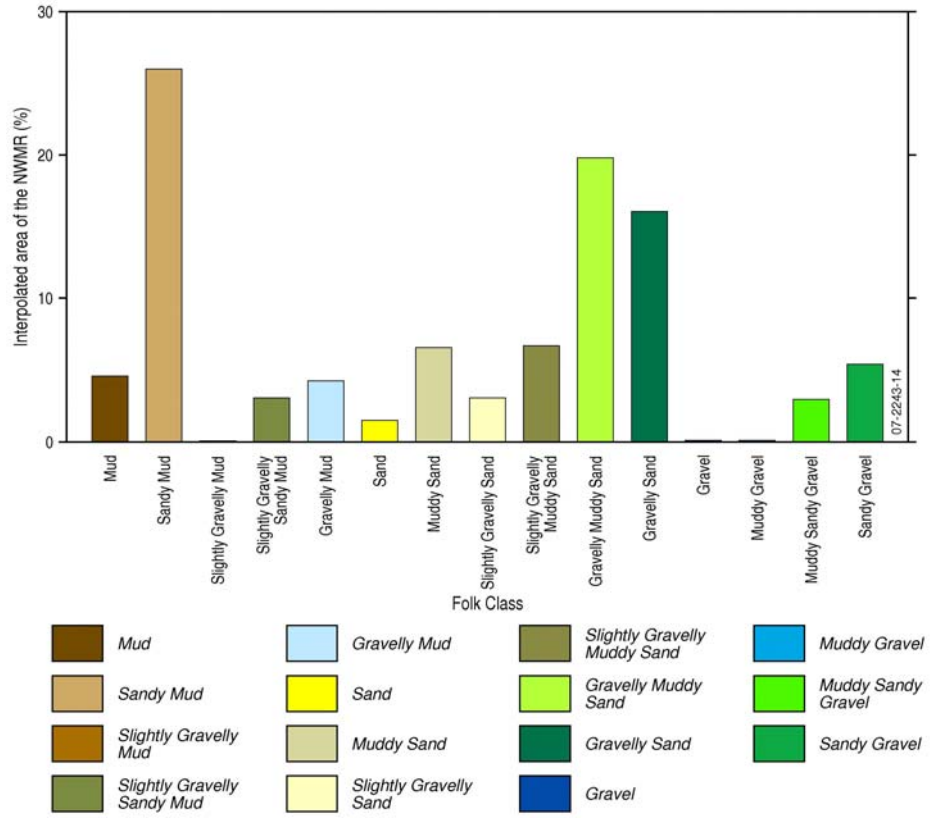


Figure 4.15. a) Interpolated grainsize data displayed as Folk Classes and b) area covered by each class expressed as % of the interpolated area of the NWMR.

4.1.4.2. Sedimentology of Geomorphic Provinces and Significant Features of the NWMR

Quantitative sedimentology is reported for features judged significant at a planning region scale that attain adequate sample coverage. These features cover a large percentage of the NWMR, represent a relatively large percentage of the total area of this feature in the EEZ, or are judged to be unique to the NWMR based on physical properties such as size or water depth range. Where occurrences of a feature form distinct groups based on morphology or water depth, each group has been described separately. Where a feature is judged as significant but does not attain adequate data coverage, features are noted as significant at a planning region or bioregion scale and properties and distribution of sediment within these features are where possible, assessed from previous literature and summarised in Chapter 6.

Features that cover smaller areas of the NWMR but are abundant locally may be judged significant at a bioregion scale. Where samples achieve coverage of only local occurrences of features, for example canyons (Mermaid Canyon, NWP) and deepwater terraces (Rowley Terrace, NWT), the sedimentology of these features is assessed in the context of the bioregion in which they occur.

Shelf Province

The shelf in the NWMR is represented by 449 grainsize and 358 carbonate assays. Over most of the area of the shelf, seabed sediment is characterised by sand (>60%), with less gravel and/or mud (Figs 4.16b & 4.17a). Sand forms >60% of sediment at 293 sites sampled, and >90% at 109 sites. Mud forms >60% of sediment at 28 sites sampled, and >90% at seven sites. Gravel forms >60% at 25 sites sampled, and >90% at seven sites. Sediment containing significant proportions of mud (>20%) are generally restricted to the outer shelf. Sediment containing >40% gravel is also concentrated on the outer shelf, but samples containing up to 80% gravel occur locally on the mid and inner shelf. At the few sites where samples provide coverage of areas on the inner shelf in close proximity to the shoreline, assays indicate that textural composition of sediment in these regions varies greatly, with mud and gravel contents exceeding 90% locally. Variation in sediment composition in these areas occurs at scales smaller than can be detected by existing sample spacing.

In the north of the planning region, on the northern Rowley and Sahul Shelves, sediment containing large proportions of mud and gravel is present across the entire width of the shelf, particularly in the area of the Londonderry Rise and Bonaparte Depression. Approximately 40% of samples from this area contain sediment that is composed of >60% sand.

Carbonate content of sediment exceeds 75% in 242 samples from the shelf and exceeds 90% in 149 samples from the shelf (Fig. 4.17a). Where samples contain gravel, carbonate content of this fraction exceeds 50% at all sites, and exceeds 80% at all except five sites (two of these occur near the coast on the Rowley Shelf). Carbonate content of the sand fraction ranges from 13 to 100% and exceeds 50% in 202 (93%) samples. The exception to this occurs in the Joseph Bonaparte Gulf, where carbonate sand forms <50% in 17 (38%) of the 45 samples in the region. Carbonate content of the mud fraction ranges between 31 and 90% and exceeds 50% in 34 (74%) samples.

Samples containing <50% carbonate are restricted to the following main areas: The Joseph Bonaparte Gulf, Bonaparte Depression and inner shelf adjacent to Port Hedland. Carbonate content varies most significantly in the shallow water areas of the Bonaparte Gulf, where it ranges from <20 to 100%. Carbonate content across the entire Bonaparte Gulf exceeds 50% in <10% of samples however it is frequently <20%. Carbonate content of sediment in this region increases across the shelf outward toward the EEZ boundary.

Slope Province

The slope in the NWMR is represented by 508 grainsize and 456 carbonate assays; these are located mainly near the shelf break. Mud is the dominant fraction across most of the Slope, though spatial clustering of assays means that overall statistics for the province do not reflect this (Fig. 4.16c & 4.17b). Sediment texture is zoned with water depth, with gravel and sand contents decreasing and mud content increasing with increasing water depth.

Mud content of samples on the upper slope varies from <1 to 97% however, sediment composition in this area is highly variable with 134 samples containing <20% mud, reflecting the sedimentology on the adjacent shelf, and approximately 173 samples containing >50% mud. On the middle and lower slope, mud content exceeds 80% at 63 sites sampled and exceeds 60% at more than 161 sites sampled.

Gravel content forms <1% of the sediment fraction at 269 sites sampled. All samples containing >1% gravel were collected within 100 km of the shelf break. Gravel content at these sites ranges from 1 to 92% with the exception of one sample which attained 100% adjacent to terrace and slope features with similar sediment characteristics. 239 samples contained <20% gravel.

Sand content of slope sediment ranges from 3 to 100% with 291 samples exceeding 50%, but it rarely exceeds 40% in areas more than 100 km from the shelf break. Sand ranges from 10 - 40% at >90% of sites sampled on the middle and lower slope.

Carbonate content of sediment on the slope ranges from 41 - 99% with 455 samples containing >50% bulk carbonate. Sediment on the upper slope generally contains >80% carbonate. Mid to lower slope sediment shows variable bulk carbonate content with no apparent zoning with water depth (Fig. 4.17b).

Carbonate content of mud present on the slope shows zoning with water depth. Where sampled, mud on the upper slope contains >80% at approximately 75% of sites. Carbonate content of mud in this area is rarely <60%. Consistently low carbonate content of mud occurs in the far north west of the NWMR on Ashmore Reef. Carbonate content of mud on the lower slope varies but ranges between 60 and 80% at approximately 80% of sites sampled.

Carbonate content of gravel is measured mainly on the upper slope near the shelf break and at 166 sites exceeds 80%. Carbonate content of sand exceeds 80% at 202 sites sampled. These are distributed across all areas of the slope.

The abyssal plain/deep ocean floor in the NWMR is represented by eight grain size and seven carbonate assays. A total of 42 additional assays from extensions of these features outside the NWMR are also used in the analysis. Sediment from the abyssal plain/deep ocean floor is dominated by mud, comprising >80% mud at approximately 90% of sites sampled (Fig. 4.16a & 4.17c). Samples generally contained no gravel and <10% sand, although one sample attained 18% sand. Bulk carbonate varies from <1 to 79%, with sediment on the Argo Abyssal Plain generally comprising <20% carbonate, while points on the Cuvier Abyssal Plain contain carbonate ranging from 40 to 79% (Fig. 4.17c).

Assays with low mud content and significant sand (ratios <1:1) all occur outside the NWMR. These samples also frequently contain higher carbonate contents than observed within the NWMR. These environments may also occur in the area of the abyssal plain/deep ocean floor within the NWMR but are not detected there due to sparse samples.

Banks/shoals

38 grain size and 39 carbonate assays were obtained from banks/shoals. Sand is the dominant fraction with contents ranging from 1 to 97% (Figs. 4.18a & 4.19a); a total of 19 of the 39 samples contain >50% sand. 10 samples recovered adjacent to basin and terrace features contain lower sand contents of between 1 and 39%. The remaining material is mud, making up between <1 and 92% of sediment volume. 11 samples contain >50% mud, and mud content is >95% in two samples which occur adjacent to sill features. These samples also contain low bulk carbonate contents (<22%) (Fig. 4.19a). Sediment in basins contain <20% gravel in 21 of the 38 samples. However, at one site adjacent to a deeps/holes/valleys feature, one sample comprises 100% gravel. Bulk carbonate content generally varies between 21 and 98% with 29 samples containing >50%. Carbonate sand content ranges between 38 and 100% and attains 100% in 15 samples. Carbonate gravel content varies from 90 to 95% in six samples.

Deep/hole/valleys

A total of 131 samples were obtained from deeps/holes/valleys. Sand is the dominant fraction ranging between 3 and 100% with 91 samples contain >50% sand (Figs. 4.18b & 4.19b). Mud is the next most abundant fraction, ranging in content from <1 to 98% with 20 samples containing >50%. Gravel attains 63% and attains 85% in three samples with a total of six samples exceeds 50%. Bulk carbonate content varies between 42 and 99% with 99 samples exceeding 70% content (Fig. 4.19b). Carbonate sand content varies from 67 to 100% with four samples attaining 100%. Carbonate mud content ranges between 33 and 91% with 31 samples exceeding 70%. Carbonate gravel content varies between 90 and 100% but attains 55% in one sample, with 29 samples attaining 100%.

Basins

A total of 26 samples were obtained from basins. At a planning region scale, basins show a common sedimentology that distinguishes them from other geomorphic features (Fig. 4.18c & 4.19c). Mud is the dominant fraction; Contents range between 9 and 97%, and a total of 15 of the 26 samples containing >50% mud. Four samples recovered from near the shelf break contain lower mud contents, ranging between 9 and 33%. The remainder of sediment volume comprises sand ranging in content from 3 to 66%, although two samples occur in an area of low mud content and contain 76% sand. Sediment in basins generally contain no gravel. However, low gravel content (1-23%) is observed occasionally at a range of locations in basins sampled. Bulk

carbonate content generally varies between 29 and 72%, where data is available (Fig. 4.19c). Carbonate sand content ranges from 27 to 100% and attains 100% in 12 samples. No carbonate mud or gravel contents were measured for existing samples in basins due to small sample volumes available for analysis (<10g).

Reefs

A total of three samples were obtained from reefs. Sand is the dominant fraction with contents ranging from 52 to 94% (Fig. 4.18d) Gravel is the next most abundant fraction with contents attaining 30%. Mud attains 35% where sand content is low. Laser grainsize distribution for this sample is included in Appendix F. Bulk carbonate content of sediment ranges from 64 to 97%.

Ridges Located in Shallow Water

A total of 18 grain size and 17 carbonate assays were obtained from ridges located in shallow water (<200 m). Mud is the dominant fraction with contents ranging from between <1 and 76% and exceeding 50% in 11 samples (Figs. 4.18e & 4.19d). Sand is the next most abundant fraction with contents ranging from 23 to 99% and dominating the sediment (>80%) in five samples. Gravel content is generally <10%, although in two samples located adjacent to terrace and slope features gravel ranges from 20 to 36%. Bulk carbonate content of sediment exceeds 80% in all but one sample (Fig. 4.19d). Carbonate mud content ranges between 88 and 89% in six samples. Carbonate sand content ranges between 93 and 98%, and carbonate gravel varies from 60 and 100% and attains 100% in six samples.

Plateaus on the Shelf or near the Shelf Break

A total of 24 grain size and 22 carbonate assays were obtained from plateaus located on the shelf or near the shelf break. Sand is the dominant size fraction in sediments; Contents range from 25 to 100% with a total of 17 samples containing >50% sand (Figs. 4.18f & 4.19e). However, one sample from the slope adjacent to a pinnacle contains <5% sand. Mud is the next most abundant fraction with contents generally ranging from <1 to 44% with a total of eight samples containing >20% mud. Gravel content ranges from 3 to 100% with five samples containing >50%. Bulk carbonate content generally varies from 17 to 99% with a total of 19 samples containing >50% carbonate (Fig. 4.19e). Carbonate sand ranges between 14 and 99% with 10 samples exceeding 50%. Carbonate mud ranges between 31 and 90%. Carbonate gravel attains 95% for five samples.

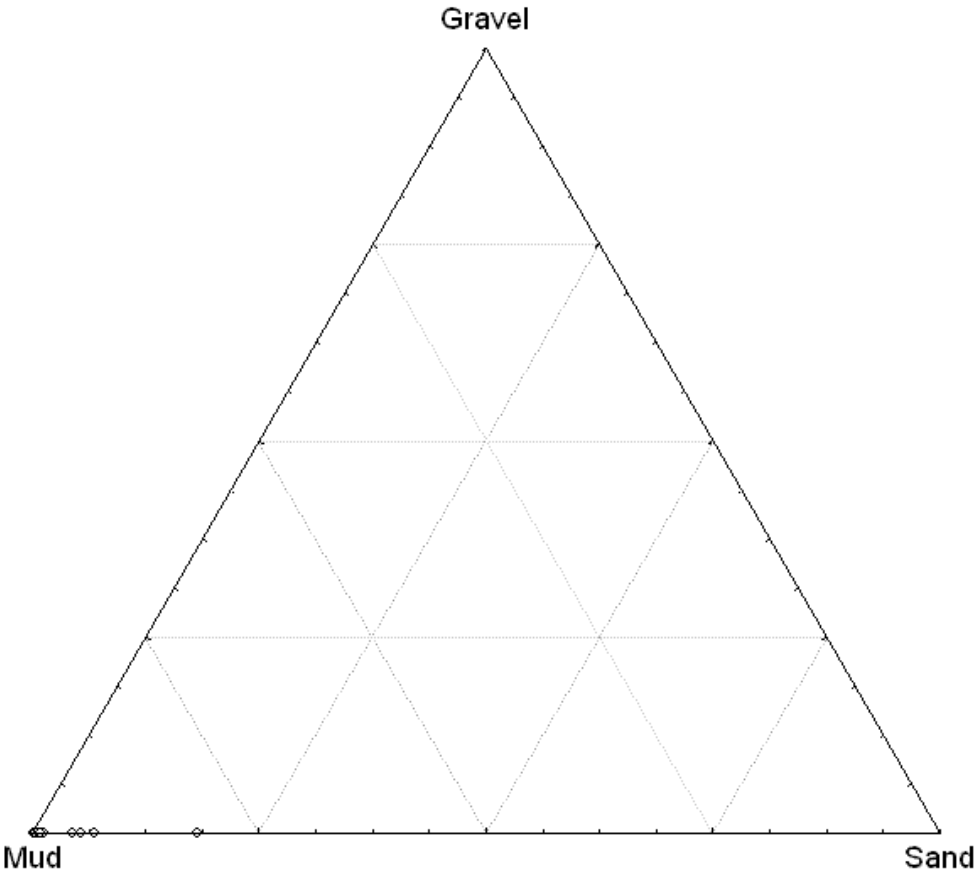
Offshore Plateaus and Terraces

A total of 37 grain size and 36 carbonate assays were collected from offshore plateaus and terraces. Mud is the most abundant fraction; Contents range from 10 to 93% with 28 samples containing >50% mud. Sand is the next most dominant size fraction with contents generally range from 6 to 89% (Figs. 4.18g & 4.19f) and exceed 50% in seven samples. Two samples did not contain sand, mud or gravel volumes adequate for analysis. Gravel content is <2% in all samples. Bulk carbonate content ranges from 50 to 88% with 28 samples containing >70% carbonate (Fig. 4.19f). Carbonate sand content ranges between 85 and 99% with 21 samples

exceeding 90%. Carbonate mud content varies from 51 to 87% with 20 samples exceeding 70%. Carbonate gravel content attains 100% in seven samples.

Terraces Located on the Shelf or Near the Shelf Break

A total of 193 samples were collected from terraces located on the shelf or near the shelf break. Sand is the dominant fraction in sediment with contents generally ranging from 8 to 100% (Figs. 4.18h & 4.19g); a total of 143 of the 193 samples contain >50% sand. Mud is the next most abundant fraction and highly variable, with contents ranging from <1 to 91%. A total of 34 of the 193 samples contain >50% mud. Gravel content ranges from <1 to 88%, and attains 100% in one sample; a total of five samples contain >50% gravel. Bulk carbonate content of sediment generally ranges from 42 to 99% with 167 samples exceeding 50% carbonate content (Fig. 4.19g). Carbonate sand content varies between 58 and 99% with 68 samples exceeding 80% content. Carbonate mud content ranges from 44 to 90% with 29 samples exceeding 60%. Carbonate gravel content varies between 90 and 100% and attains 100% in 24 samples.



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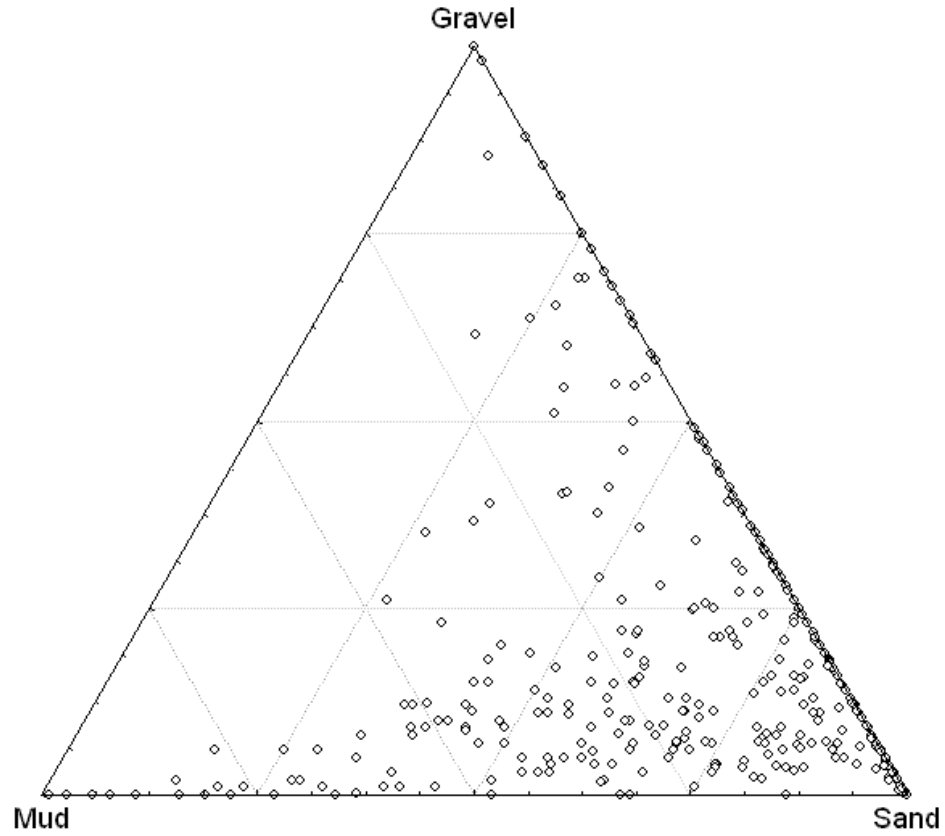

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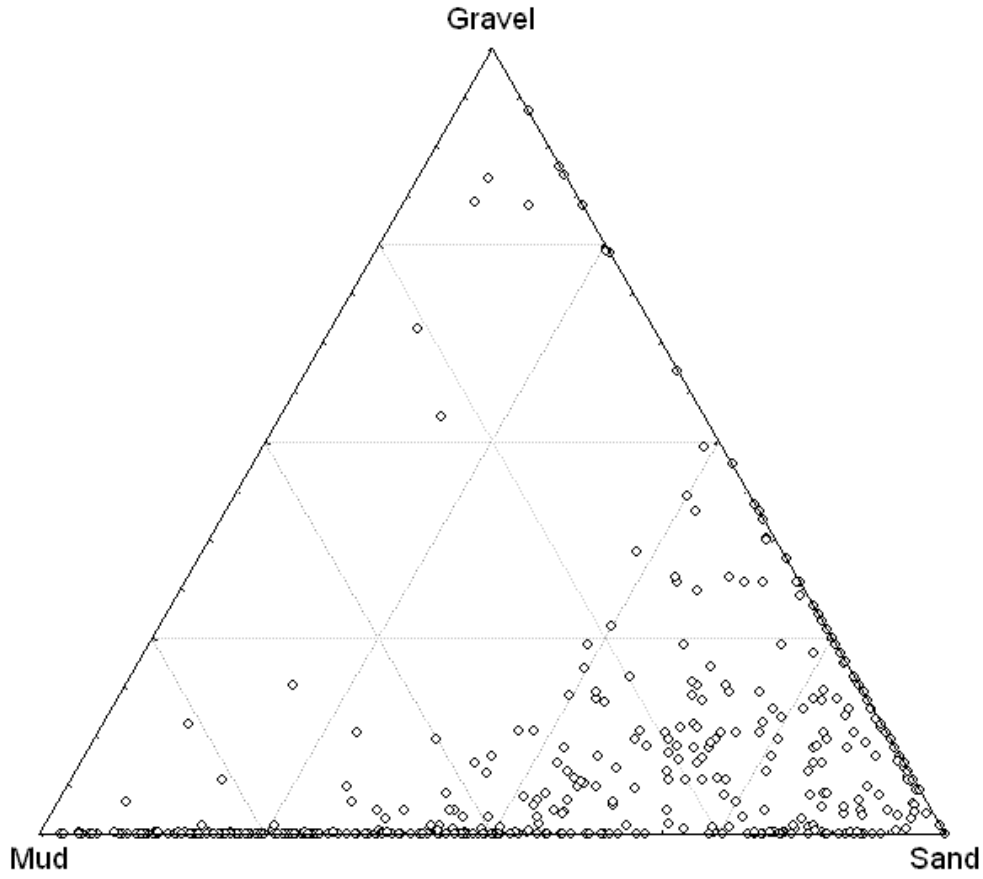

Figure 4.16. Textural composition (mud:sand:gravel ratio) of geomorphic provinces in the NWMR: a) abyssal plain/deep ocean floor province; b) shelf province; and c) slope province sediments within the NWMR.

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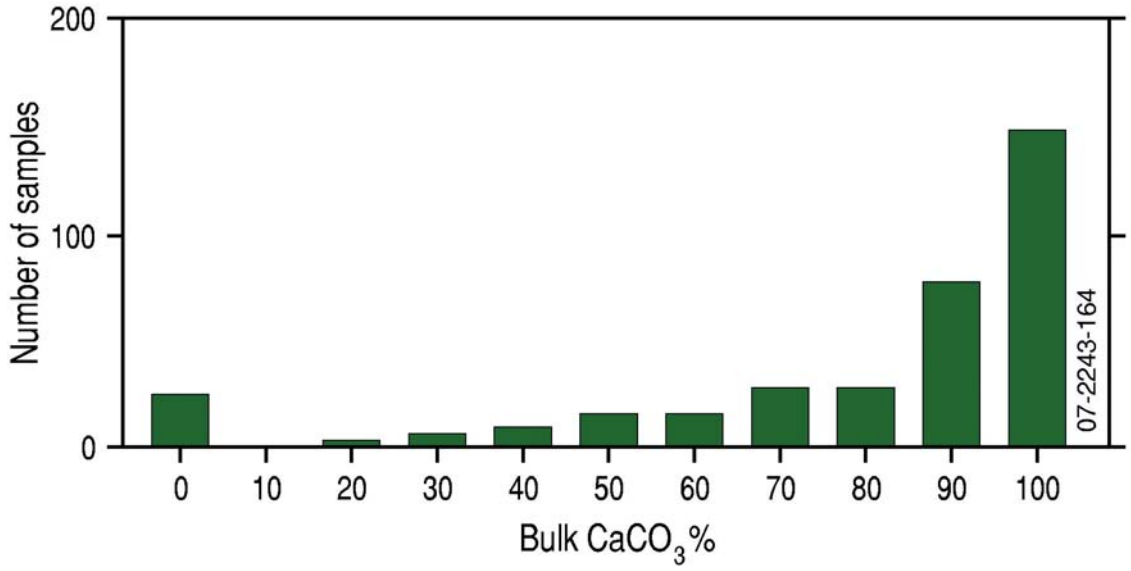
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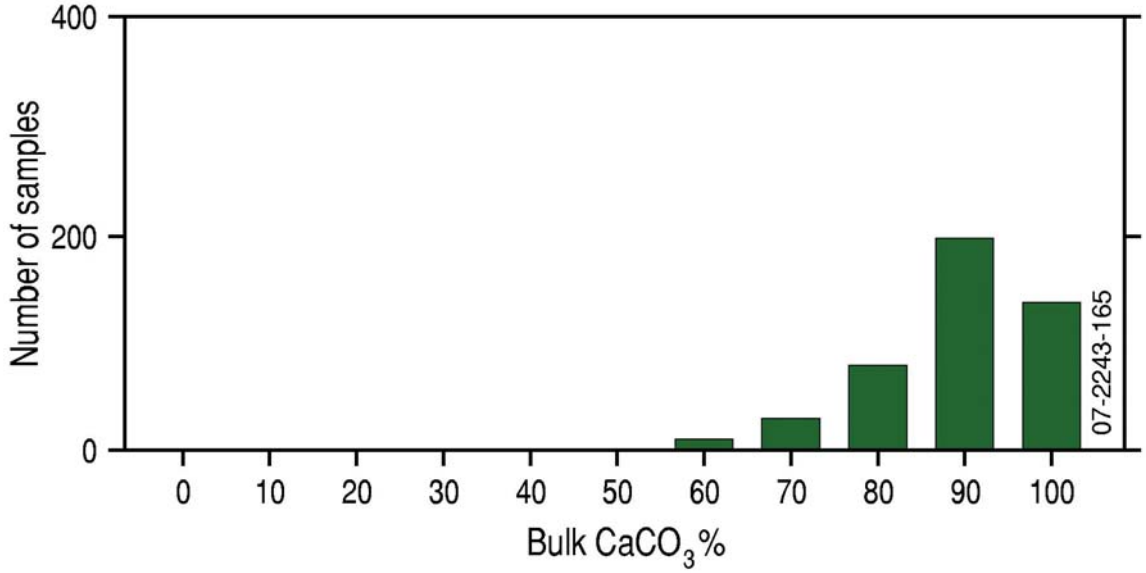
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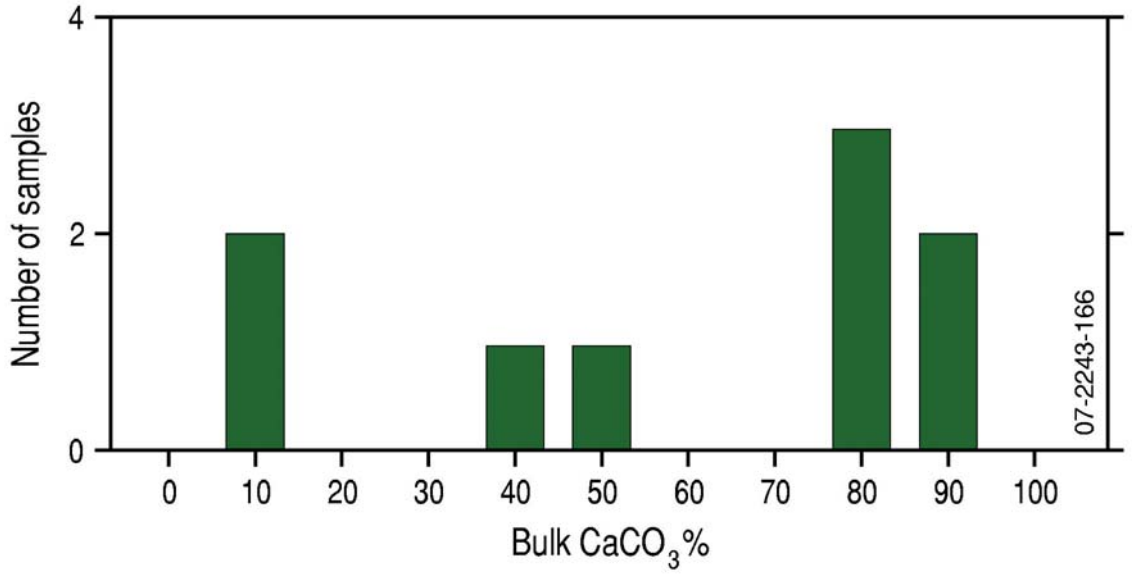
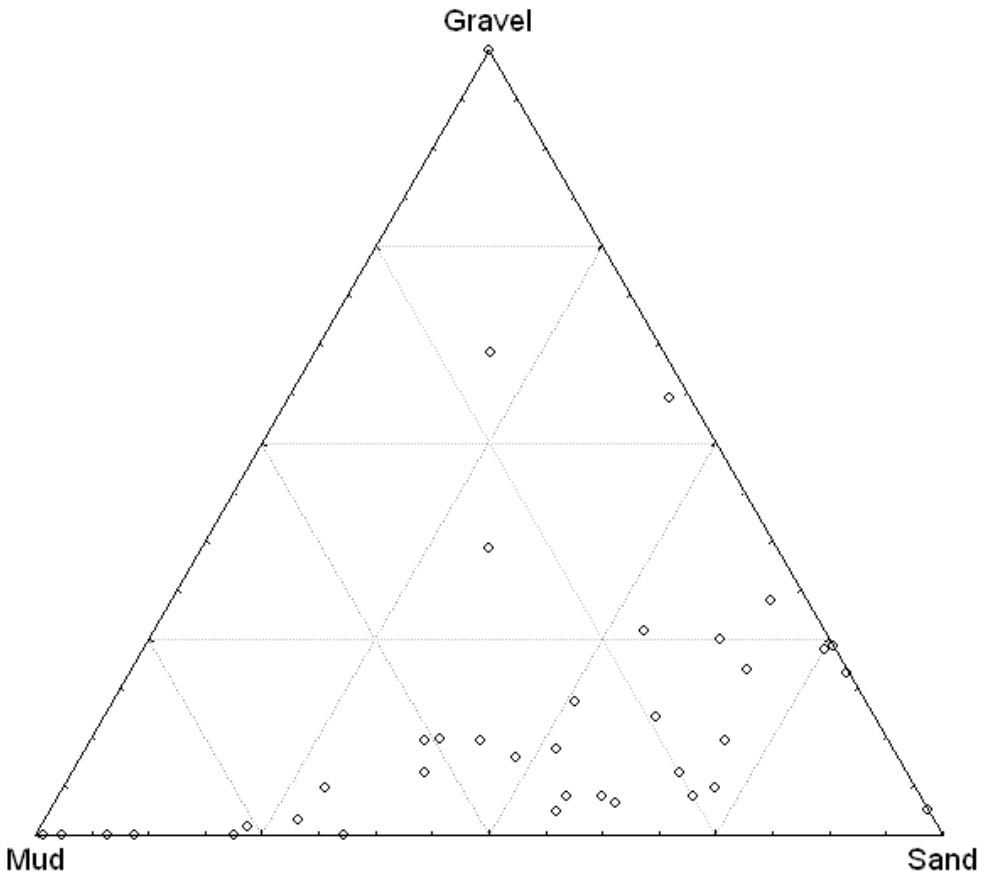


Figure 4.17. Carbonate content of geomorphic provinces within the NWMR: a) shelf province; b) slope province; and c) abyssal plain/deep ocean floor province.

a)



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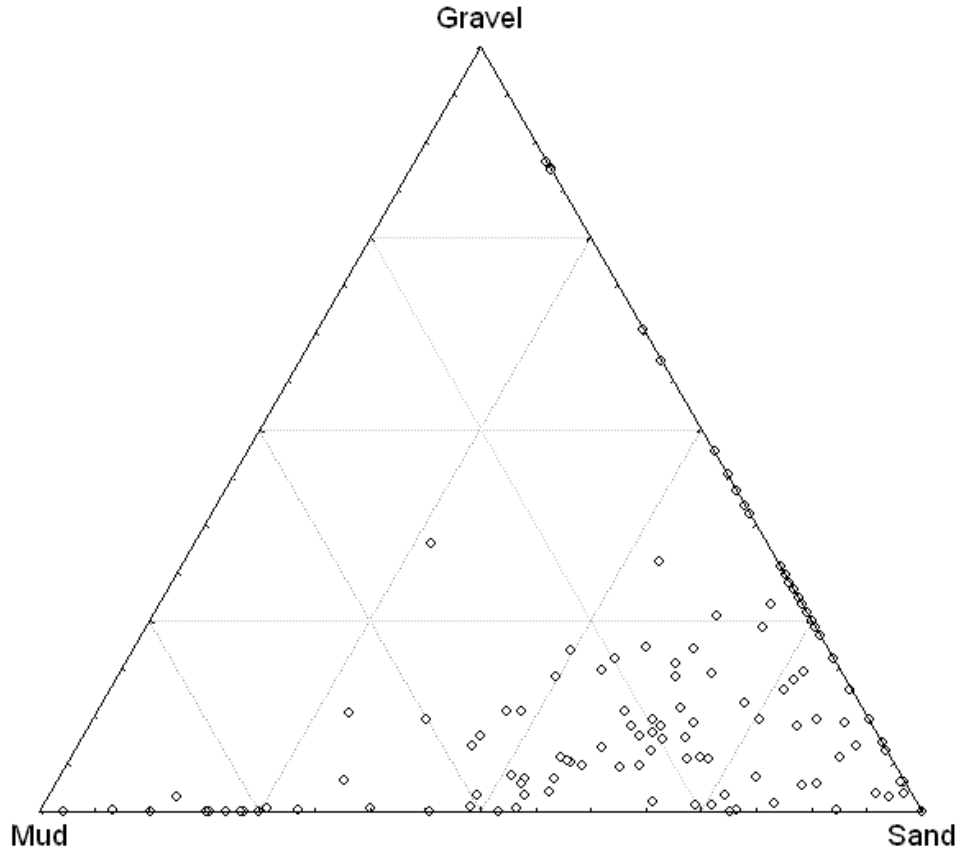
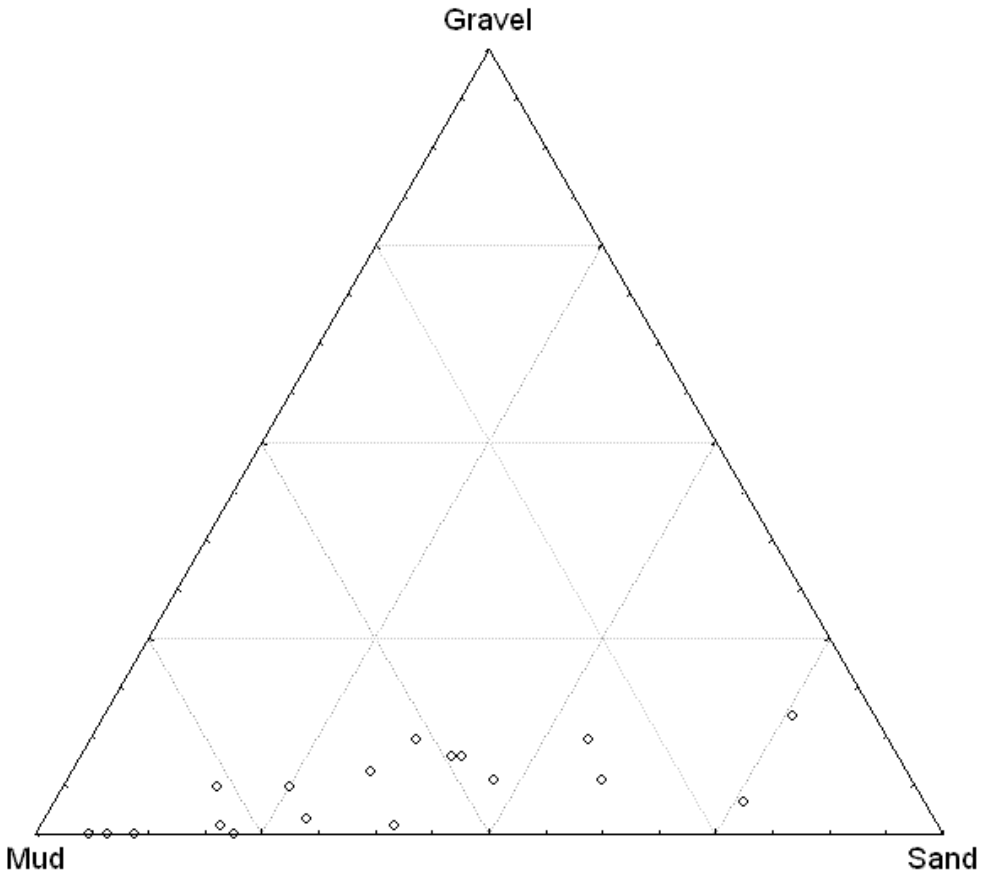
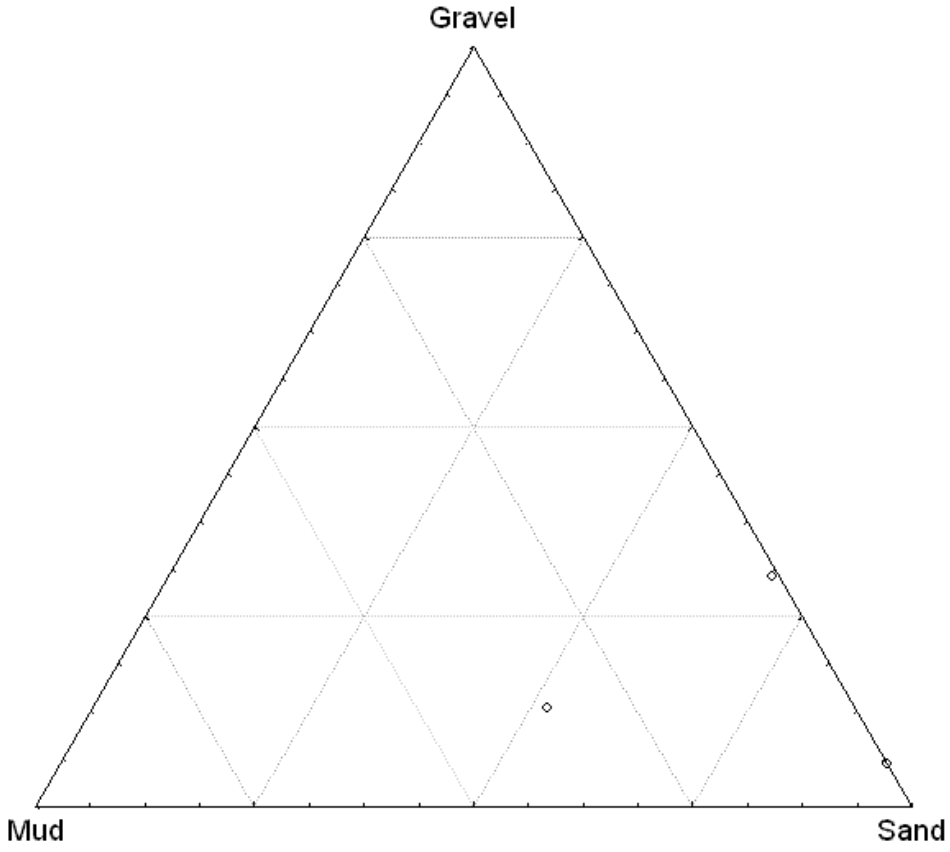
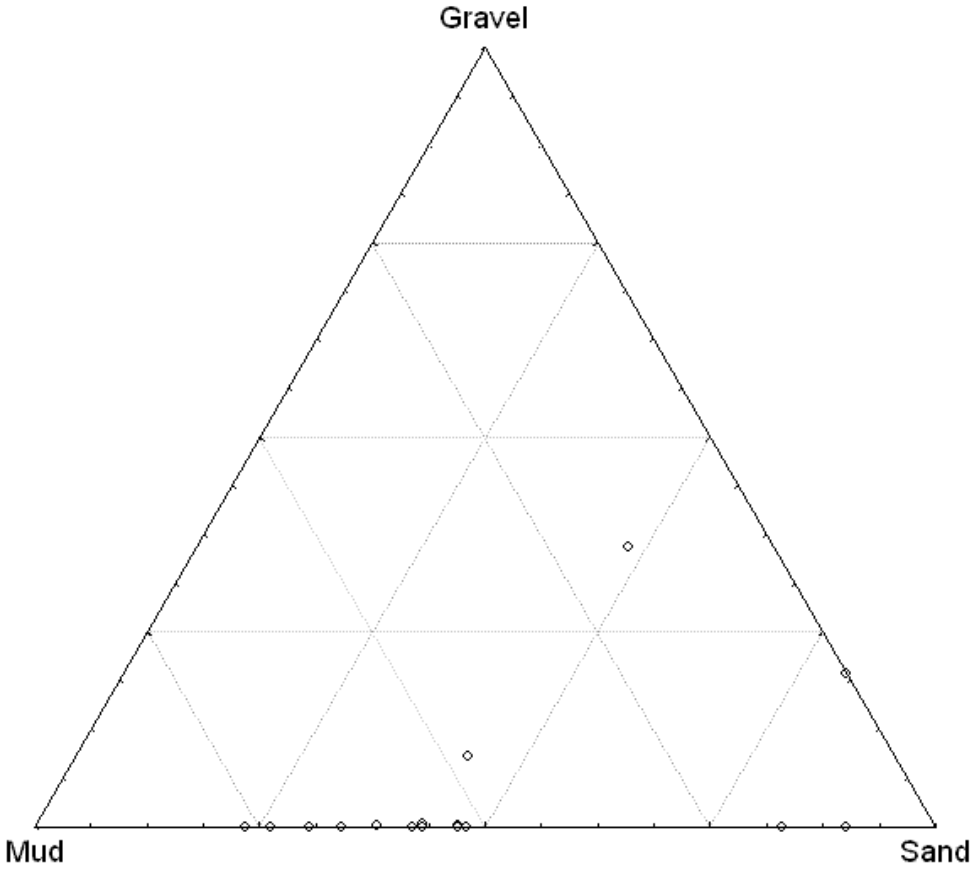




c)

d)





e)

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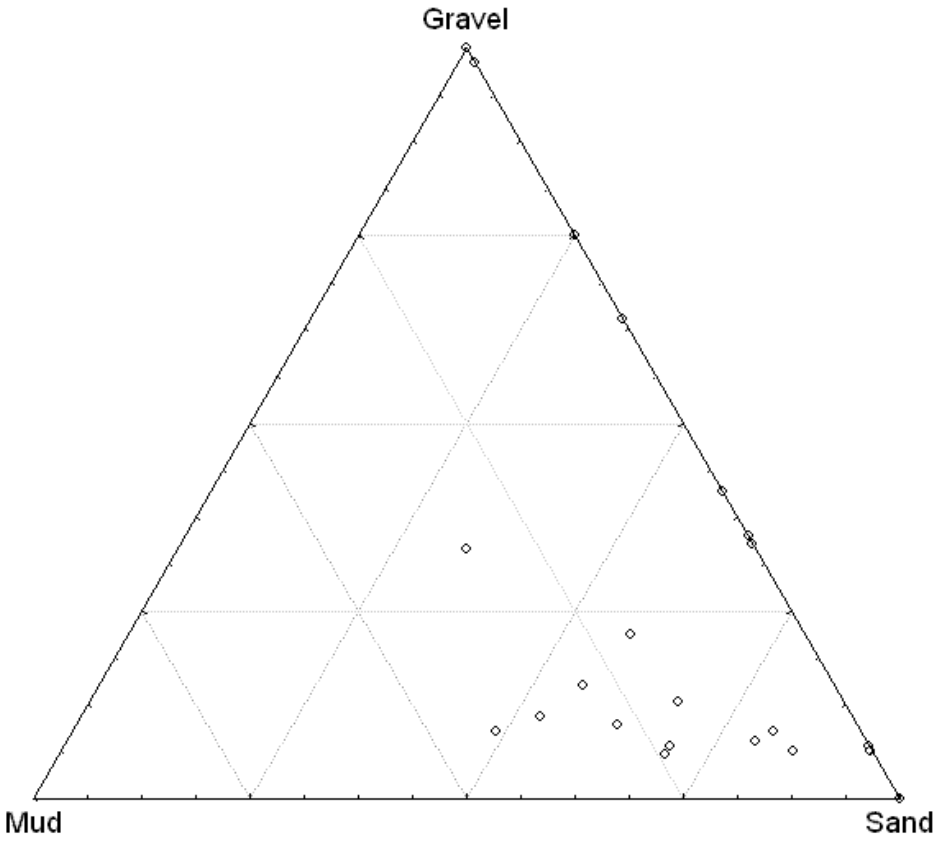

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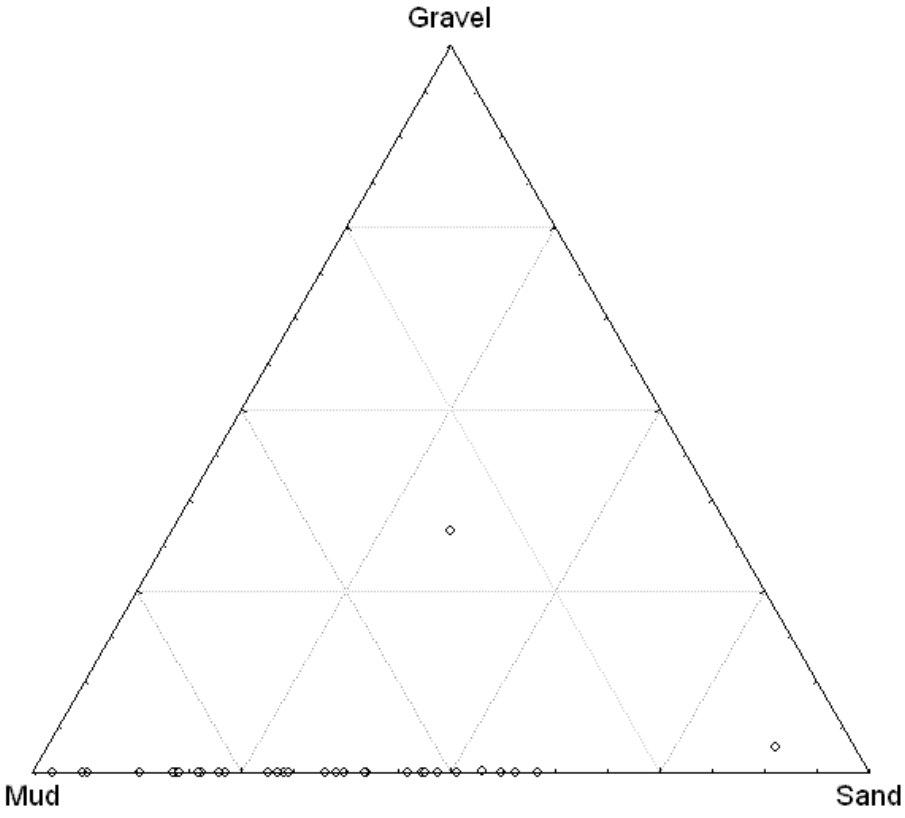

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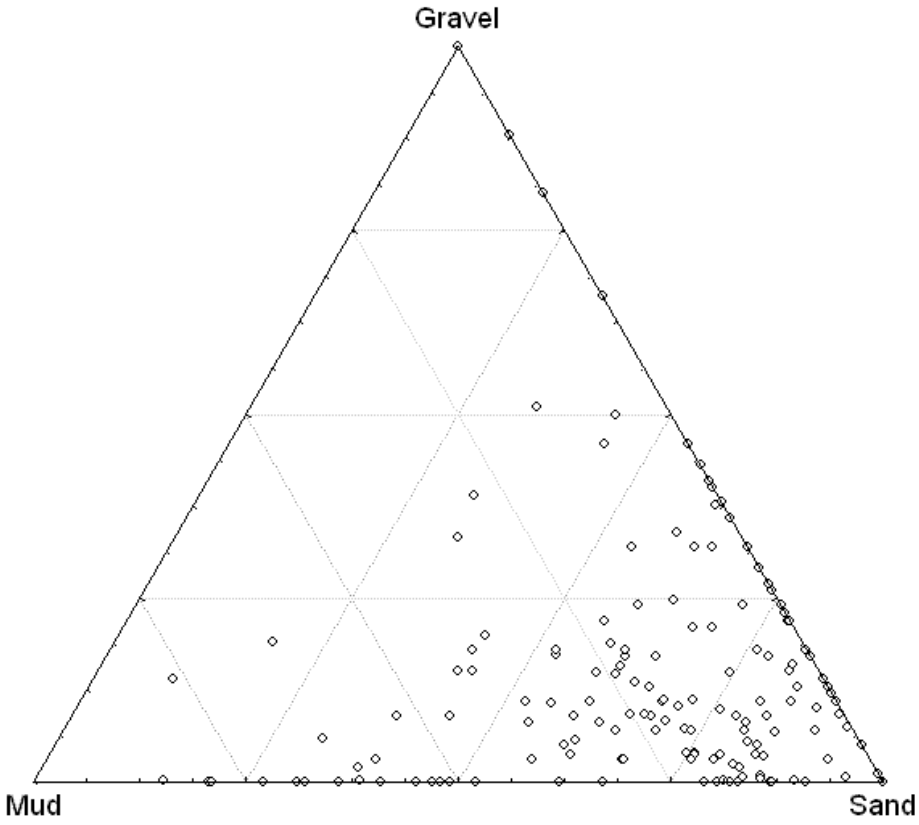

Figure 4.18. Textural composition (mud:sand:gravel ratio) of significant geomorphic features in the NWMR: a) bank/shoal; b) deep/hole/valley; c) basin; d) reef; e) ridges located in shallow water; f) plateaus on the shelf or near the shelf break; g) offshore plateaus and terraces; and h) terraces located on the shelf or near the shelf break.

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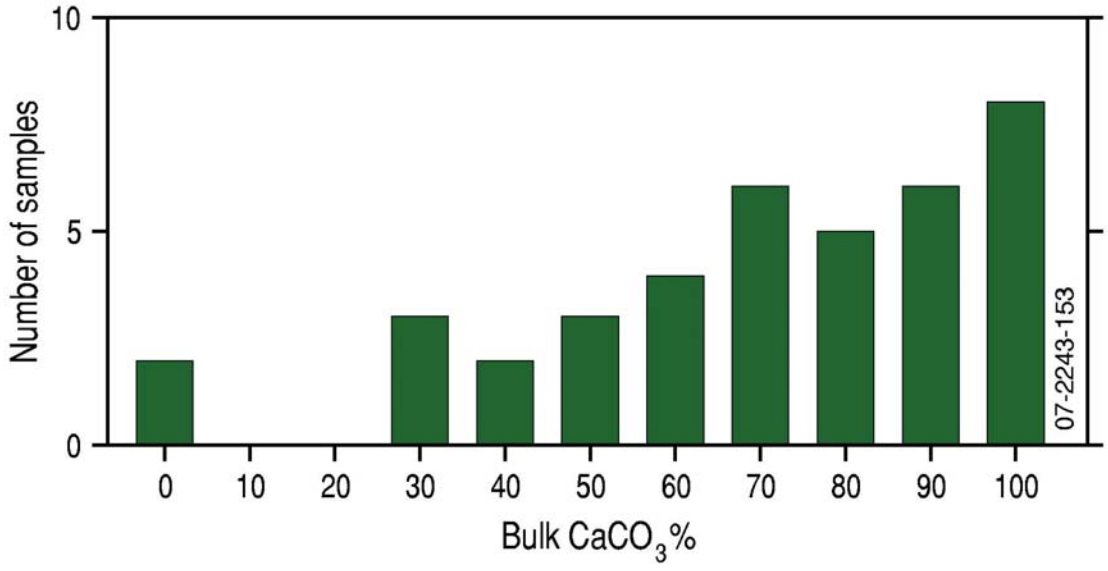

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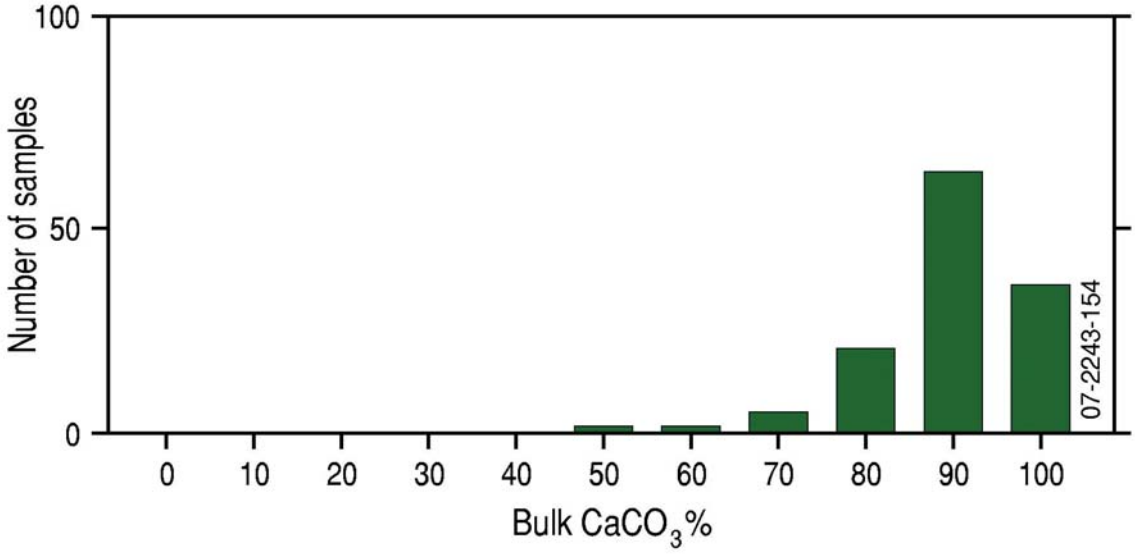
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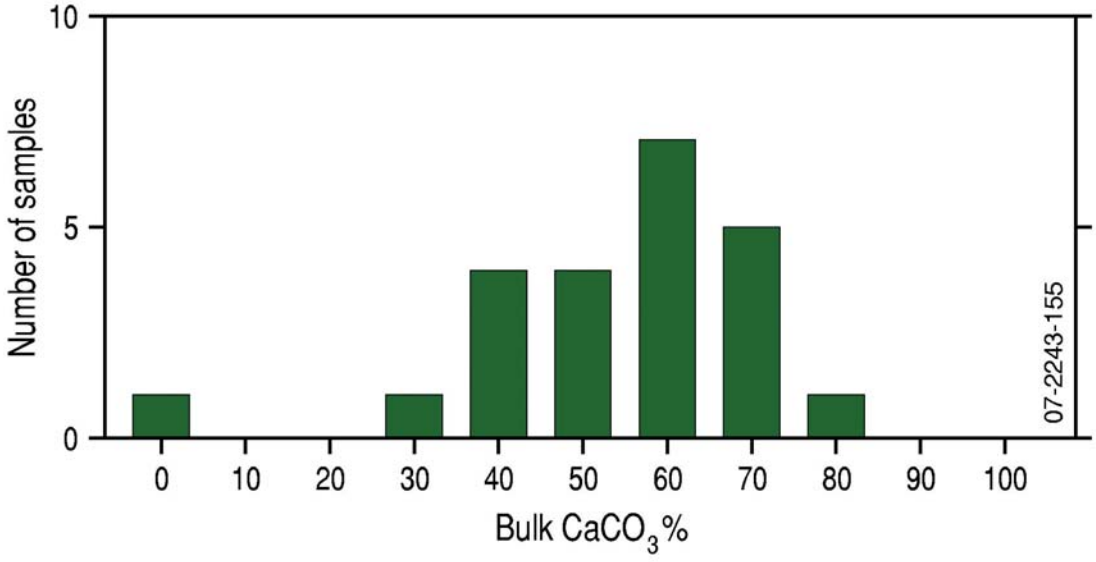
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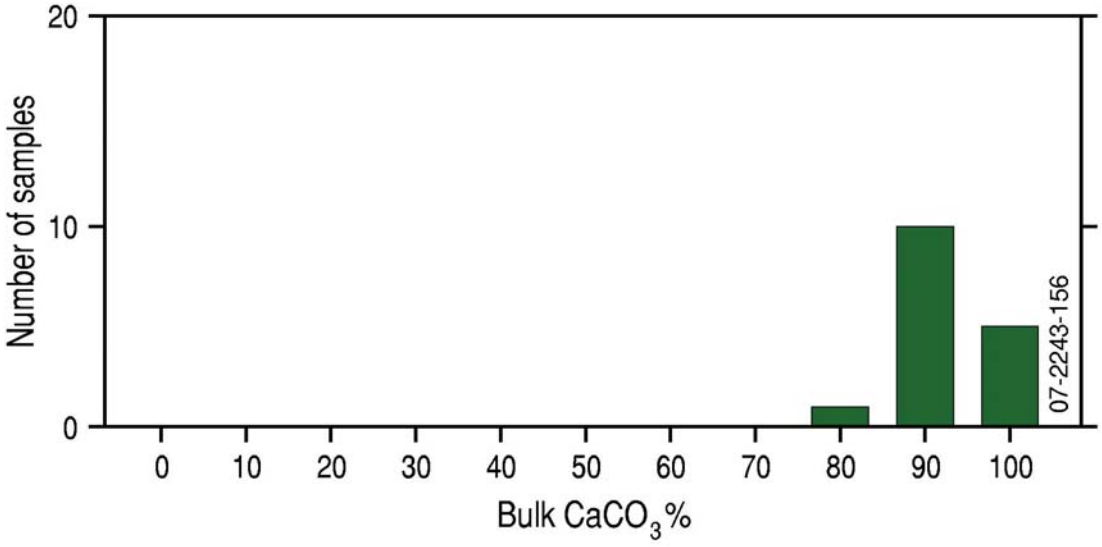
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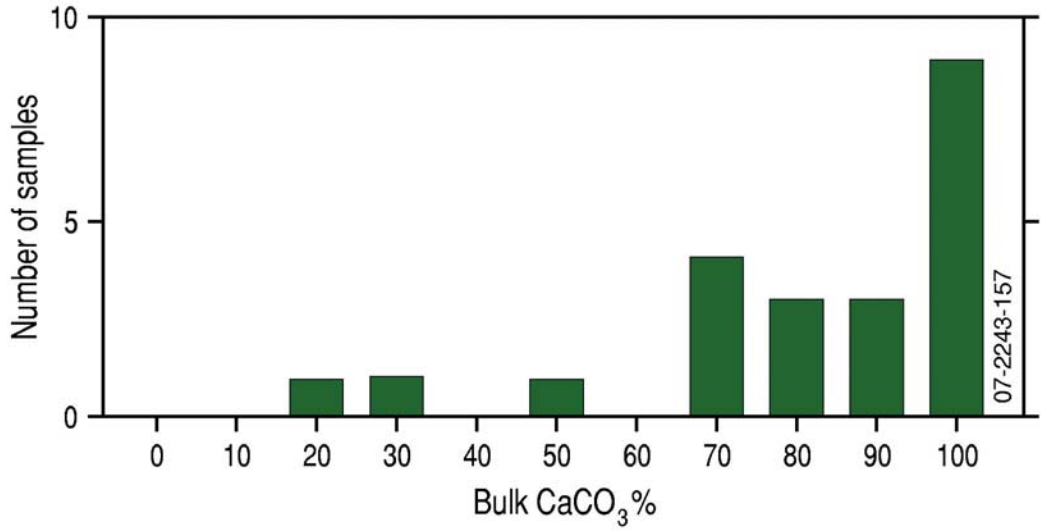
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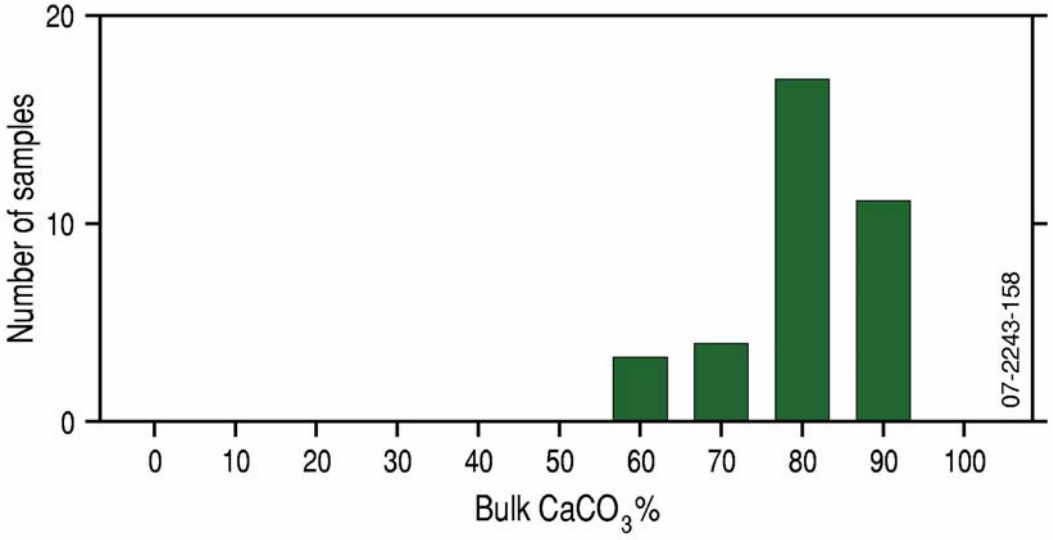
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