MINERALOGICAL VARIATION WITHIN THE MARINE SEDIMENTS OF THE DAMPIER REGION : A DYNAMIC APPROACH

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ABSTRACT

Sediments of the Dampier Archipelago and surrounding areas are composed of carbonates derived from coral, coralline algal and invertebrate skeletal debris. The carbonate-rich mineralogy contrasts with that of the Precambrian crystalline metasediments and igneous bedrock which forms much of the archipelago.

The ratios of aragonite, Mg-high and Mg-low calcite and silicates vary greatly within the area and are indicative of the variation in the physical dynamics which control the biological diversification therein.

1. INTRODUCTION

The recent development of iron-ore, salt and liquified natural gas terminals in the Dampier Archipelago, Nickol Bay and Port Walcott area ($2200\ km^2$, $20^{\circ}20'-20^{\circ}45'$ S and $116^{\circ}25'-117^{\circ}20'$ E) in the north-west of Australia (Fig. 1a) has given increased impetus to the study of this marine environment. Existing environmental pressures are seen in heavy metal contaminated oysters adjacent to sewage and coolant water outfalls (Talbot 1985), increased coral mortality close to dredging (Simpson 1985), and increased light attenuation in the waters adjacent to anthropogenic discharges.

Little is known about the coastal processes in this area. Treloar (1978) noted that information concerning the physical, chemical and biological processes are essential in order to predict the long-term effects of the development in the area. Studies of mobile sediments can reveal certain hydrographic conditions controlling the transport and deposition of solid materials in an area (Imran, 1963).

This bulletin discusses :

1. the genesis of the marine sediments and the distribution patterns of the mineral components; and

2. the relationships between mineral diversity, marine habitat diversity and the physico-chemical dynamics of the area.

2. GENERAL CLIMATE AND ENVIRONMENT OF THE STUDY AREA

The area is arid-tropical, dominated by high evaporation and low rainfall (Gentilli, 1972). Mean monthly temperatures range from 37.1°C in February to 26.3°C in June-July, while seawater temperatures vary between $20-32^{\circ}$C in the inner regions and between $22-29^{\circ}$C in the more exposed areas. Maximum rainfall occurs in May with mean annual recordings of

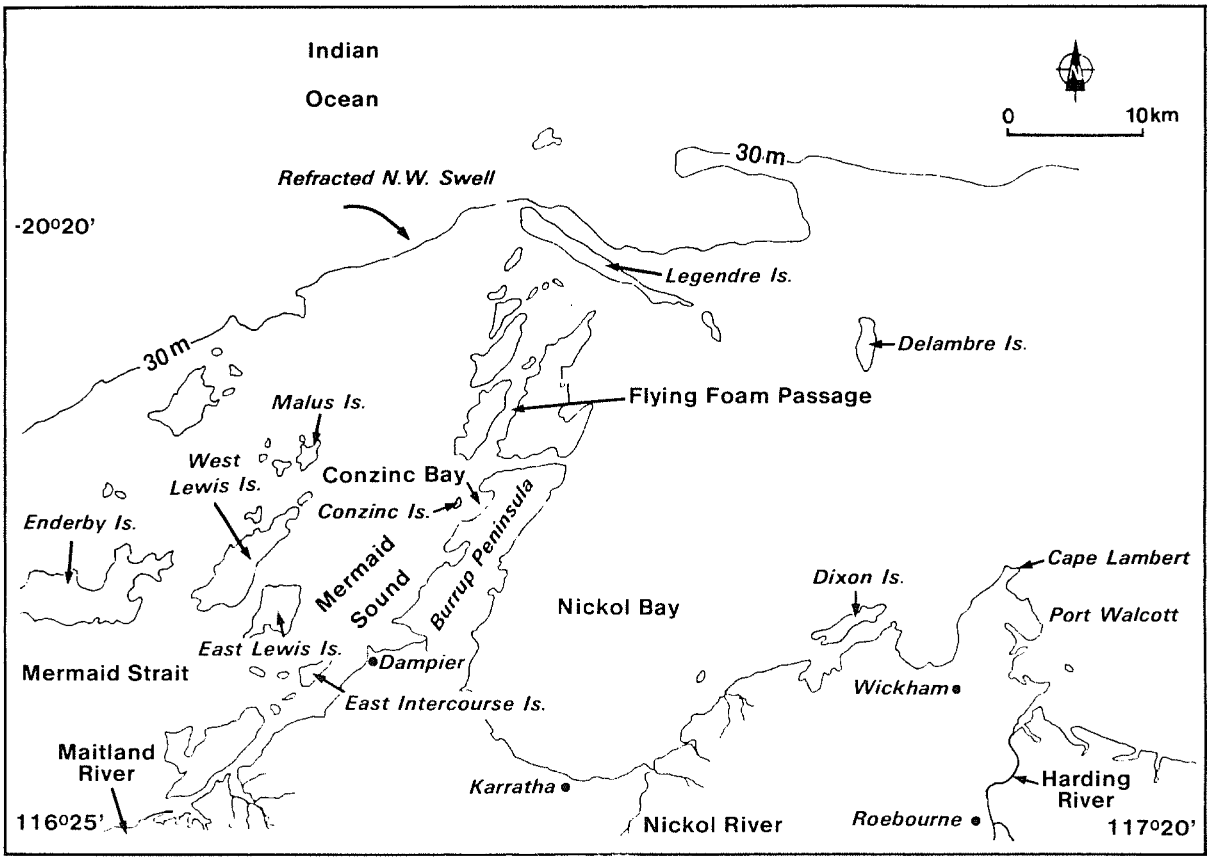

Fig. 1a. Study area.

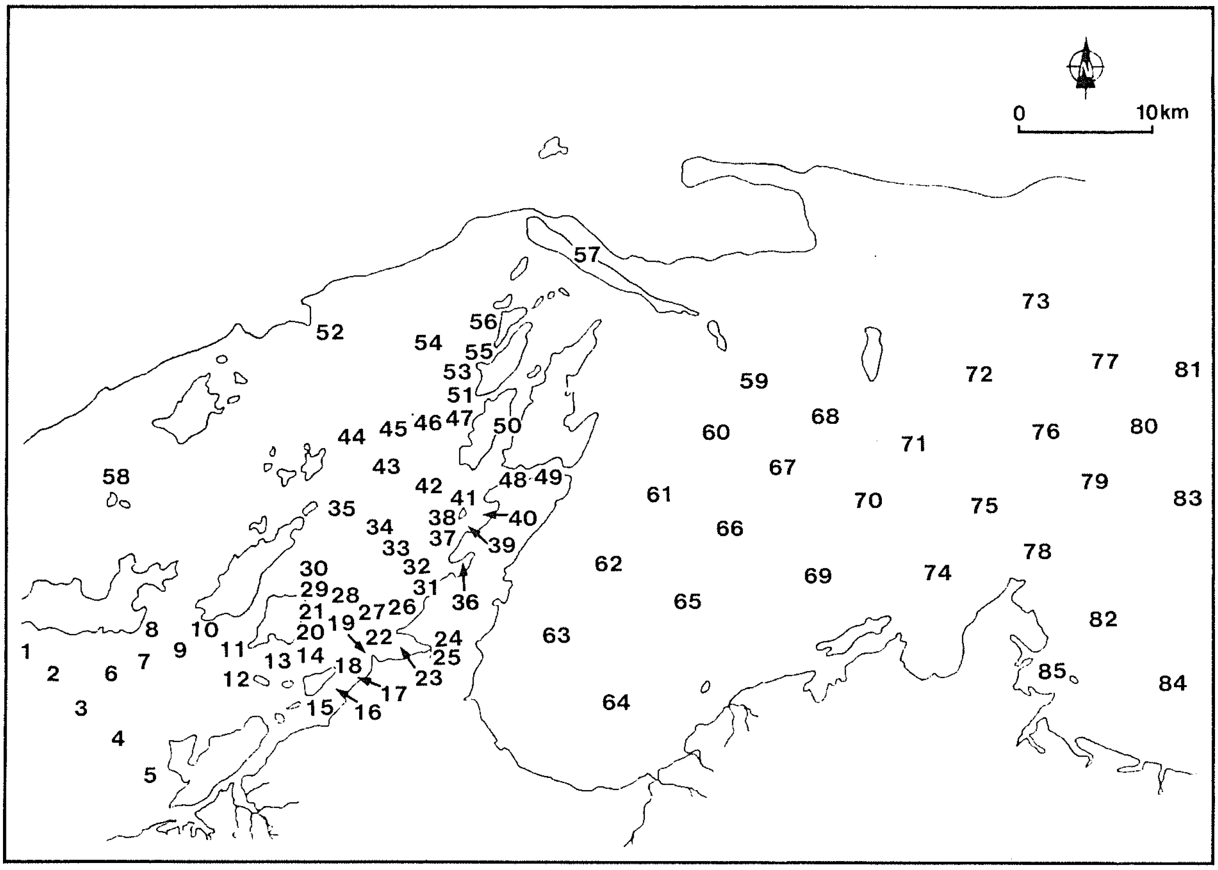

Fig. 1b. Sampling locations.

315 mm and a total of only 33 rain-days per year. Evaporation ranges from 384 mm in December to 193 mm in July (Semeniuk et al., 1982).

Cyclones pass within 100 km of this coastline every 2-3 years, between December and April (Coleman, 1971). At such times wind gusts may reach velocities of up to 63.9 m/s (Bureau of Meteorology, pers. comm). Forde (1985) has suggested that the greatest disturbance of the marine ecosystem in this area occurs when offshore cyclones move in a south-westerly direction parallel to the coastline. The most persistent strong winds are south-westerlies and westerlies which blow in summer and generate ocean swell. This swell in turn transmits energy in an east to north-easterly direction along the continental shelf (D A Mills, Department of Conservation and Environment, pers. comm.). Such swell is refracted into the Dampier Archipelago as a result of a submarine escarpment along the 30 m contour (Fig. 1a) and transmits sufficient energy to the waters of the study area to provide for the transport of sediments (Forde, 1985). When the wave energy transgresses the escarpment, some of it is attenuated. Under cyclonic conditions, however, the attenuation is not sufficient to protect coral and algal communities from widespread destruction.

As in most coastal environments, precipitation strongly influences the rate of erosion, transport and deposition of sedimentary material (Holmes, 1972). Fluviatile discharges are restricted to the Maitland, Nickol and Harding Rivers (Fig. 1a)(C Nicholson, Department of Conservation and Environment, pers. comm.). Cyclones that cross the coast north-east of the study area and move inland, however, tend to produce strong easterly winds and heavy rain over the Pilbara region, which result in sheet flooding into the study area. As the area is naturally arid and pastoral practices have taken little account of soil stability, erosion is widespread and the drainage systems are not able to cope with cyclonic rains. The result is the intermittent transport of large quantities of sediment-laden freshwater which spill into the study area, particularly in the Nickol Bay region (C Nicholson, Department of Conservation and Environment, *pers. comm.*)(Figs. 2a and 2b).

The coastline has large semi-diurnal tides, mean spring range is 5.6 m, mean neap range is 1.0 m and water velocities up to 0.5 m/s are known (Easton, 1970).

Since the late pleistocene the sea level has risen by 60 m around Australia (Kriewaldt, 1964). Kriewaldt also noted, however, a small drop of 0.6 m in sea level in the study area during the past 2000 years. The overall change in sea level has resulted in an inundated land mass with basement rock forming most of the outcrops and some overlying Quaternary limestones and sandstones (Anon, 1979, 1980; Semeniuk *et al.*, 1982). The outcrops in the Dampier Archipelago are frequently precipitous, being the remnants of the tops of a once untransgressed landmass. This is particularly evident along the Burrup Peninsula and to a lesser extent along Cape Lambert (Fig. 1a).

3. METHODS

3.1 Sediment Collection and Storage

Marine sediments (1 x 5 kg bulk sample) were collected from the top 30 mm at 85 sites (Fig. 1b), using either SCUBA or a pipe-dredge from a boat depending on water depth and visability. Samples were stored at room temperature in the field and subsequently dried at 60°C for 24 h and stored in sealed plastic vials.

3.2 Mineralogical Analyses

Methods of preparation and analysis followed those of Hutchinson (1974). Determinations were carried out on a Rigaku-Denki X-Ray Generator-D-90 interfaced with a goniometer-SG7. Angles of 2 were used covering a 5°-45° range and the system was coupled to

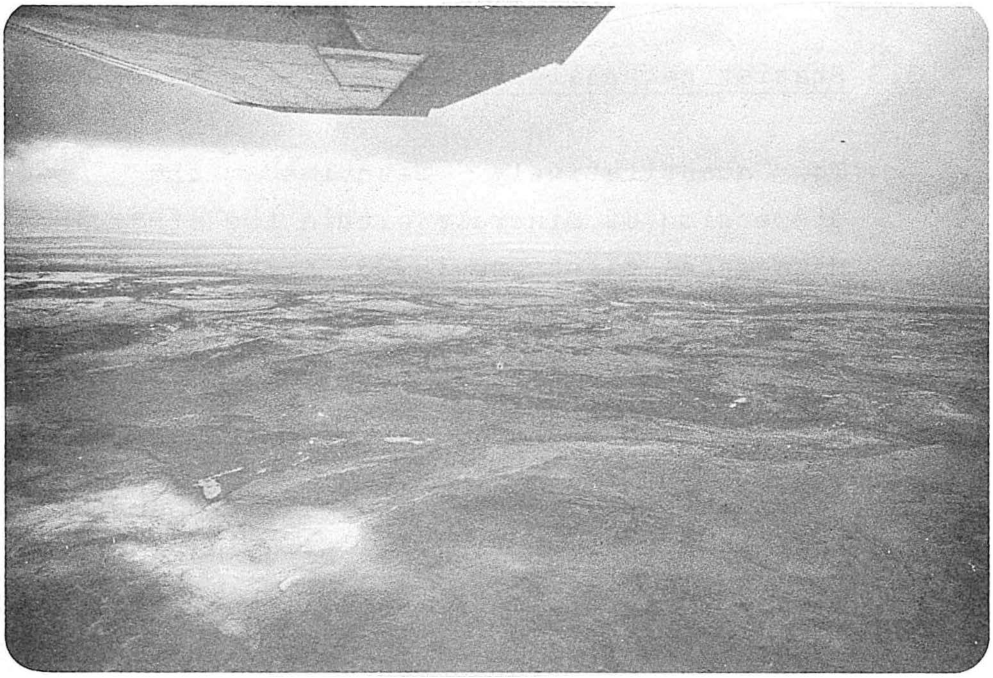

Fig.2a: The Harding River hinterland, photographed in February 1984, one day after heavy rain. The area shown is about 7 km^2.

Fig.2b: The Maitland River mouth, photographed in February 1984, one day after heavy rain. This type of flooding also occurs at the Harding River mouth during similar weather conditions. The area shown is about 7 km^2. Photographs: C. Nicholson.

an ECP-TS print-out unit.

3.3 Statistical Analyses

To quantitatively describe the geographical dispersion of minerals within the study area, the raw data were first reviewed and samples grouped by geographical locations and/or exposure to oceanic swell. Groups were then compared using Student's t-test (Zar, 1974).

Correlations between mineral dispersion patterns throughout the study area were determined using a hierarchial cluster analysis, STATPACK (Houchard, 1974). The data were subsequently divided into sub-sets on a geographical basis (east and west of the Burrup Peninsula) and a mineralogical basis (sites with high carbonates and low silicate values, and sites with low carbonate and high silicate values), and correlation coefficients calculated for each sub-set.

Throughout results and discussion, unqualified references in statistical tests to 'random' or 'significant' relationships indicate comparisons at the 1% probability level ($P = 0.01$). All means are expressed as mean ± standard error (SE). Where 'high' values and 'low' values are referred to in the text these represent values falling in upper and lower 15% of the data range (see Appendix 1).

4. RESULTS

4.1 General Sediment Description

Mineralogical analyses revealed the marine sediments to be dominated by carbonates (aragonite, high-magnesium calcite :12-17 mole% $MgCO_3$, low-magnesium calcite :2-3 mole% $MgCO_3$) with increasing quantities of quartz, feldspars (mainly

K-feldspar) and clays (mainly kaolinite) in the shallower and more sheltered areas (Appendix 2). The composition of these sediments is in marked contrast with the composition of the exposed crystalline Precambrian countryrock and suggests there is little mineralogical relationship between the modern marine sediments of the area and the detritus from the terrigenous rock.

4.2 Geographical Dispersion of Minerals

4.2.1 Aragonite

Significantly higher ($P<0.05$, $t = 2.12$) proportions of aragonite were found in the sediments of the Dampier Archipelago than in sediments of the Nickol Bay-Port Walcott area (Appendix 2). Values in the Dampier Archipelago ranged from 3.2% to 48.3% with mean (±SE) value of 18.6±1.3%, and a predominance of high values occurring along subtidal regions of the near shoreline area where coral habitats were dominant (e.g. sites 8, 10, 17, 24, 29, 32, 36, 38, 41, 47, 56, 58).

4.2.2 Low-Magnesium and High-Magnesium Calcite

Sediments in the outer more exposed reaches of Nickol Bay (e.g. sites 59, 61, 68, 71-73, 75, 77, 80, 81) contained a significantly higher ($P<0.05$, $t = 2.48$) proportion of low magnesium calcite than sediments at remaining sites closer to the shoreline (Fig. 1b; Appendix 2).

In general sediments of the Nickol Bay-Port Walcott area possessed slightly higher relative proportions of low magnesium calcite than sediments to the west of the Burrup Peninsula in the Dampier Archipelago ($P<0.01$, $t = 2.99$). Values to the east of the Peninsula ranged from 14.0-56.7% with a mean of 33.8 ± 2.2%, while those west of the Burrup ranged from

4.0-54.0% with a mean of 30.1 ± 1.2%.

In contrast to the distribution of low-magnesium calcite, high-magnesium calcite occurred predominatly in the mid to outer waters of Mermaid Sound in the Dampier Archipelago. For example, sites 35, 37, 39-40, 42-45, 51 and 53-55 revealed values ranging from 44.3-57.3%. Values were significantly lower ($P<0.001$, $t = 5.04$) in regions exposed to freshwater runoff and in sheltered areas of low wave energy (e.g. sites 5, 8, 13, 14, 18, 19, 23, 24, 25, 63-65, 74, 84, 85). Sediments at these sites contained relative proportions of high-magnesium calcites <17.5%.

4.2.3 Quartz

The quartz content of sediments was found to be significantly greater ($P<0.05$, $t = 2.64$) in the more sheltered and shallow areas adjacent to the coastline. For example, sediments at sites in the inner reaches of the Nickol Bay-Port Walcott area (sites 62-66, 74, 84, 85) and sites in Mermaid Sound between Conzinc, East Lewis and East Intercourse Islands, all possessed a quartz content of >30%. In such areas the water was generally turbid, exposure to freshwater runoff more likely, and coral communities were scarce.

4.2.4 Feldspars and Clays

Quantities of feldspars and clays detected at the majority of sites in the Nickol Bay-Port Walcott area, were low (<1.0%). Where higher values occurred they were generally restricted to sites in the inner well-sheltered regions of the Bay; for example, sites 63-65, and 85 possessed values for feldspars between 5.4% and 8.9%, while sites 76, 78 and 84 possessed values for clays between 1.3% and 2.0%. To the west of the Burrup Peninsula, feldspars and clays were found at sites in the inner reaches of Mermaid Sound between Conzinc Island and West Intercourse Island, and in Mermaid Strait, east of Eaglehawk Island. A relatively high proportion of clay was also detected in sediments at site 44 in the deeper, more exposed waters north of Malus Island which is a precipitate Precambrian outcrop (Fig. 1a; Appendix 2).

The maximum levels of clays (3.0-3.9%) were recorded in Mermaid Strait, Mermaid Sound and Flying Foam Passage (sites 3-5, 7, 10, 11, 27, 44, 48, 50) and levels of up 22.6% were recorded for feldspars at site 25 in King Bay.

It should be understood, however, that X-Ray diffraction techniques can only be used in a semiquantitative manner for these classes of minerals at the concentrations encountered during this study. In the authors opinion these minerals are likely to be present in quantities greater than those actually recorded.

4.3 Mineralogical Correlation Matrices

4.3.1 Correlations for Data from all Sites

Results of the correlation analysis for the study area as a whole are given in Table 1. Values with a common function in each variable correlated were deleted as they were expected to have naturally high correlation coefficients.

Significant inverse relationships ($P<0.001$) were found between the two major classes of minerals present in the area, carbonates and silicates, and in particular between total carbonates and quartz ($P<0.001$, $r = -0.978$). Of the 14 sites where high feldspar values occurred (Appendix 2) only one site, site 25, possessed high values for all three carbonate polymorphs. This site was at the entrance

TABLE 1.

Matrix correlation coefficients (r) for selected mineralogical variables for entire study area.
**P<0.005, ***P<0.001

		A	C	Mg-C	Q	CL	F	$\frac{\text{TC}}{\text{TS}}$	$\frac{\text{C+Mg-C}}{\text{A}}$	$\frac{\text{C}}{\text{A}}$	$\frac{\text{Mg-C}}{\text{A}}$	$\frac{\text{C}}{\text{Mg-C}}$	$\frac{\text{A}}{\text{Mg-C}}$	$\frac{\text{C+A}}{\text{Mg-C}}$	$\frac{\text{C}}{\text{A}}$	$\frac{\text{TC}}{\text{Ts}}$
Aragonite	A	-														
Calcite	C	-0.118	-													
Magnesium-calcite	Mg-C	-0.084	-0.032	-												
Quartz	Q	-0.438***	-0.542***	-0.415***	-											
Clays	CL	-0.054	-0.240	-0.280**	0.238	-										
Feldspars	F	-0.291**	-0.422***	-0.410***	0.597***	0.230	-									
Total Carbonate	TC	-	-	-	-0.978***	-0.284**	-0.724***	-								
	$\frac{\text{C+Mg-C}}{\text{A}}$	-	-	-	-0.062	-0.092	-0.150	-	-							
	$\frac{\text{C}}{\text{A}}$	-	-	0.038	-0.070	-0.030	-0.032	-	-	-						
	$\frac{\text{Mg-C}}{\text{A}}$	-	0.215	-	-0.207	-0.098	-0.257	-	-	-	-					
	$\frac{\text{C}}{\text{Mg-C}}$	-0.089	-	-	0.217	0.116	0.339***	-	-	-	-	-				
	$\frac{\text{A}}{\text{Mg-C}}$	-	-0.258	-	0.219	0.127	0.390***	-	-	-	-	-	-			
	$\frac{\text{C+A}}{\text{Mg-C}}$	-	-	-	0.232	0.048	0.380***	-	-	-	-	-	-	-		
	$\frac{\text{C}}{\text{A}}$	0.274**	-	0.270	-	-0.429***	-0.274**	-	-	-	-0.799***	-	-	-	-	
$\frac{\text{Total Carbonate}}{\text{Total Silicate}}$	$\frac{\text{TC}}{\text{TS}}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

of a small river which drains an area used partly for the disposal of industrial waste. Clays were found to be randomly distributed with respect to the distribution of aragonite and calcite, though negatively correlated with high-magnesium calcite ($P<0.005$, $r = -0.280$). Such correlations indicate that the production, transportation and deposition of silicates are controlled by different processes to those generating the polymorphs of carbonate.

The inverse correlation between quartz and low-magnesium calcite ($P<0.001$, $r = -0.542$) has a higher coefficient than that for quartz and high-magnesium calcite ($P<0.001$, $r = -0.415$) suggesting quartz in some of the outer regions may have a different origin to that deposited near the mainland coast.

Correlations between feldspars and aragonite : high-magnesium calcite ($P<0.001$, $r = 0.390$), and aragonite+calcite : high-magnesium calcite ratios ($P<0.001$, $r = 0.380$) were also found to be significant. This indicates that it is the high-magnesium calcite which plays the dominant role amongst the carbonates.

Within each of the major classes of minerals, components were randomly distributed with respect to each other, with the exception of feldspars and quartz. These minerals showed a positive correlation ($P<0.001$, $r = 0.597$). This was consistent with previous observations that both minerals are found in sheltered, turbid waters, waters where Precambrian rocks are plentiful, and in areas close to points of fluviatile and stormwater runoff.

4.3.2 Correlations for Data from the Subsets East and West of Burrup Peninsula

Table 2a and b show results of correlation matrices for all sites east of the Burrup Peninsula and for all sites in the Nickol Bay-Port Walcott area to the west of the Burrup Peninsula, respectively.

In the Nickol Bay-Port Walcott area quartz and feldspars were again found to be inversely correlated ($P<0.005$) with carbonates, however, clays showed significant inverse relationships with only one carbonate polymorph, high-magnesium calcite ($P<0.005$, $r = -0.343$). In contrast, silicates in sediments of the Dampier Archipelago showed distributions that were only inversely correlated ($P<0.005$) to that of low-magnesium calcite (quartz $r = -0.863$; clay $r = -0.590$; feldspars $r = -0.547$). The dominant carbonate east of the Burrup Peninsula would thus appear to be low-magnesium calcite.

Correlations were again found between feldspars and ratios of aragonite : high-magnesium calcite ($P<0.001$, $r = 0.425$) and aragonite+calcite : high magnesium calcite ($P<0.001$, $r = 0.523$) indicating high-magnesium calcite has the most discrete dispersion pattern of all the carbonates in sediments west of the Burrup Peninsula. No such correlations, however, were found for sediments in the Nickol Bay-Port Walcott area.

In sediments for each of the subset east and west of the Burrup Peninsula, carbonate polymorphs showed random dispersion patterns with respect to each other. In the silicates, the dispersion of quartz and feldspars was again found to be positively correlated in sediments of both the Dampier Archipelago ($P<0.001$, $r = 0.750$) and the Nickol Bay-Port Walcott area ($P<0.001$, $r = 0.610$).

TABLE 2a

Matrix of correlation coefficients (r) for selected mineralogical variables for subset east of the Burrup Peninsula.

$**P<0.005$, $***P<0.001$

		A	C	Mg-C	Q	CL	F	TC	$\frac{A}{Mg-C}$	$\frac{A+C}{Mg-C}$
Aragonite	A	-								
Calcite	C	-0.052	-							
Magnesium calcite	Mg-C	-0.302	0.120	-						
Quartz	Q	-0.290	-0.863***	-0.147	-					
Clays	CL	0.281	-0.590***	0.405	0.455	-				
Feldspars	F		-0.338	-0.547**	-0.610***	0.266	-		0.103	-0.015
Total Carbonate	TC	-	-	-	-0.995***	-0.467**	-0.679***	-		

TABLE 2b

Matrix of correlation coefficients (r) for selected mineralogical variables for subset west of the Burrup Peninsula.

$**P<0.005$, $***P<0.001$

		A	C	Mg-C	Q	CL	F	TC	$\frac{A}{Mg-C}$	$\frac{A+C}{Mg-C}$
Aragonite	A	-								
Calcite	C	-0.102	-							
Magnesium calcite	Mg-C	-0.041	-0.122	-						
Quartz	Q	-0.518***	-0.367**	-0.644***	-					
Clays	CL	-0.204	-0.049	-0.343**	0.373**	-				
Feldspars	F	-0.325**	-0.403***	-0.581***	0.750***	0.194	-		0.425***	0.523***
Total Carbonate	TC	-	-	-	-0.974***	-0.378**	-0.848***	-		

4.3.3 Correlations for Data from Carbonate-Rich and Carbonate-Poor Subsets

Results of correlation analyses based on mineralogy rather than geography of the study area are presented in Table 3a and 3b. Carbonate rich environments tended to be environments in the more exposed outer reaches of the study area, while carbonate-poor environments were generally close to shorelines and less exposed to oceanic swell and high wave energy.

In both environments silicates and total carbonates showed strong inverse relationships ($P<0.001$) with respect to distribution. In carbonate-poor habitats, however, this relationship was dominated by the quartz and aragonite components ($P<0.001$, $r = -0.629$), while in carbonate-rich areas the dominant components were quartz and high-magnesium calcite ($P<0.001$, $r = -0.462$). Carbonate-rich sediments were generally observed to support communities of coralline algae in addition to coral communities.

The distributions of aragonite and high-magnesium calcite were inversely related ($P<0.005$, $r = -0.399$) in carbonate-rich sediments. Silicates in these sediments also showed a strong positive correlation with respect to each other ($P<0.001$). In carbonate-poor sediments the dispersion of minerals within each of the two major classes tended to be random.

5. DISCUSSION

5.1 Mineralogical Variation

The composition of the marine sediments (mainly carbonates) in the Dampier Archipelago and Nickol Bay-Port Walcott area is in marked contrast to the composition of the exposed crystalline country.

TABLE 3a

Matrix of correlation coefficients (r) for selected mineralogical variables for carbonate-rich subset.
**P<0.005, ***P<0.001

		A	C	Mg-C	Q	CL	F	TC	$\frac{A}{Mg-C}$	$\frac{A+C}{Mg-C}$
ragonite	A	-								
alcite	C	-0.281	-							
agnesium alcite	Mg-C	-0.399**	-0.310	-						
uartz	Q	-0.129	-0.390	-0.462***	-					
lays	CL	0.102	-0.249	-0.424**	0.547***	-				
eldspars	F	0.062	-0.300	-0.305	0.496***	0.721***	-		0.164	-0.004
otal arbonate	TC	-	-	-	-0.963***	-0.566***	-0.544***	-		

TABLE 3b

Matrix of correlation coefficients (r) for selected mineralogical variables for carbonate-poor subset.
**P<0.005, ***P<0.001

		A	C	Mg-C	Q	CL	F	TC	$\frac{A}{Mg-C}$	$\frac{A+C}{Mg-C}$
ragonite	A	-								
alcite	C	0.226	-							
agnesium alcite	Mg-C	-0.011	-0.083	-						
artz	Q	-0.629***	-0.679***	-0.131	-					
ays	CL	0.007	0.170	-0.010	-0.353	-				
ldspars	F	-0.422**	-0.516***	-0.337	0.526***	-0.068	-		0.532***	0.542***
tal rbonate	TC	-	-	-	-0.962***	-0.251	-0.068	-		

Amongst these carbonates, the occurrence of aragonite is most prominent in habitats to the west of the Burrup Peninsula and along the more exposed coastlines. The occurrence of aragonite generally coincides with the presence of relatively dense coral communities (C. Simpson, Department of Conservation and Environment, pers. comm.). High-magnesium calcite also occurs predominantly in sediments to the west of the Burrup peninsula in offshore mid to outer reaches of Mermaid Sound. In contrast, the greatest concentrations of low-magnesium calcite may be found in habitats in exposed outer areas of Nickol Bay, east of the Burrup Peninsula. Thus sediments in the Nickol Bay-Port Walcott area are most likely derived from a different source to those of the Dampier Archipelago. This in turn reflects a difference in the dynamics affecting the outer reaches of both areas. The Nickol Bay region has a shallow sloping bathymetry and is exposed to extensive sheet runoff, especially at the mouth of the Nickol River and around Dixon Island. The area is sheltered from high energy long period waves because refraction of westerly and north-westerly swell along the submarine escarpment is not sufficient to allow it to enter Nickol Bay. The open waters of the Dampier Archipelago are generally exposed to "rougher" weather conditions, lower light attenuation and less terrestrially-derived suspended sediment loads. In these waters, sediment deposition is generally restricted to cyclonic conditions.

The presence of coralline algae foraminifera and echinoides may also help to explain the distribution pattern of high-magnesium calcite as this mineral is a major constituent of these biota (Chave, 1954).

Silicates generally occur in shallow, sheltered regions adjacent to coastlines and to streamwater and fluviatile discharges; for example, the inner reaches of Nickol Bay and Mermaid Sound. In such areas the water is turbid and coral communities noticeably reduced or absent.

Dredging activities have changed the bathymetry of Mermaid Sound during the past 20 years. If further dredging opened up the entrance to Mermaid Sound, it would cause an increase in erosion of the inshore habitats thus changing their community structures. On the hand, if soil erosion of the hinterland is increased as it was under the influence of pastoral development (C. Nicholson, Department of Conservation and Environment, pers. comm.), incursion of terrestrial sediments along the shoreline will also increase, reducing the number of carbonate-based communities in these areas.

The random distribution of clays with respect to carbonate may be attributed to their physical properties. Clays are platey in shape, electronegatively charged and have a greater ability to remain in suspension after crossing the freshwater-seawater interface. Due to their higher residence time in suspension, they can be transported over a broader area than other silicates and as a result show less affinity for any one area compared with the other silicates.

When viewed on a geographical basis two main mineralogical regions can be distinguished. East of the Burrup Peninsula, sediments are dominated by low-magnesium calcite, while to the west of the Peninsula sediments are rich in high-magnesium calcite and to a lesser extent aragonite. Increasing quantities of silicates, in particular quartz, occur in the shallow and sheltered areas of both regions.

On a mineralogical rather than geographical basis, however, the distribution patterns of high-magnesium calcite are largely unrelated to those of other minerals, either to silicates or to other carbonate polymorphs. This indicates that the processes which generate high-magnesium calcite are not directly related either to terrestrial inputs or process generating aragonite and low-magnesium calcite sediments.

On the basis of the dominant carbonate type, the study area may thus be considered as a series of ecological subunits resultant of the variation in dynamics within the system. The three major types which emerge are :

(1) areas adjacent to freshwater runoff which contribute large quantities of silicate-rich terrestrial material during cyclones;

(2) shoreline areas which are not inundated by suspended matter during freshwater discharges, and where there is some exposure to ocean swell, i.e. aragonite-rich sediments dominated by coral communities; and

(3) areas which are not necessarily close to the shoreline but are exposed to ocean swell, i.e. high-magnesium calcite sediments dominated by coralline algal communities.

The correlations between mineral dispersion patterns on either side of the Burrup Peninsula are quite different even though they are both carbonate-rich environments. Consequently, the physical factors which control the erosion, transport and deposition of sediments are also likely to vary between these areas.

5.2 Genesis of Carbonate Sediments

The Dampier Archipelago exhibits a number of varying carbonate-based habitat types with different community structures. The major disruption of these communities results from impinging long period waves which dissipate their energy over the shallow coral reefs (Forde, 1985). Coral communities in outer reaches of the Archipelago where wave energy is high, are more vulnerable as they constitute a high percentage of fragile branching (Acropora formosa) and tabuloid (Acropora hyacinthus) species. In contrast, species further south in the sheltered areas of Mermaid Sound are dominated by massive corals, Platygyra sinensis and Porites sp. Under cyclonic conditions species of Porites of up to 0.8 m diameter (0.7 tonnes) have been dislodged and swept across other coral species fragmenting them as they pass (Forde, 1985). In this way corals, which are rich in aragonite (Cox et al., 1982) aid in the generation of carbonate sediments. Recovery of coral reefs can be rapid (Simpson, 1985) and the constant process of fragmentation and regeneration has led to the build-up of aragonite-rich sediments in the Dampier Archipelago.

The production of high-magnesium calcite sediments also occurs during the devastation of reefs. The skeletons of coralline algae, especially those of the crest or seaward side of a reef, are rich in high-magnesium calcite (Chave, 1954) and are broken down into unconsolidated sediments during high energy conditions.

Low-magnesium calcite sediments are most likely produced through erosion of the low-magnesium calcite pleistocene cover. In addition the low-magnesium tests of oysters and echinoderm remains are present in the sediments of this area.

Under cyclonic conditions 74% of the suspended sediment load in the waters of the study area may be carbonates (Forde, 1985). Thus, not only are carbonate sediments generated in the region, but if fine enough can be transported over a wide area.

5.3 Genesis of the Silicate Sediments

The major production of silicates occurs through erosion and transport of vaste quantities of topsoil from the hinterland. Erosion of the area has been accelerated by overgrazing and mismanagement of the pastoral leases earlier this century. During the cyclone season silicate-rich terrestrial sediments are washed into the Maitland, Nickol and Harding Rivers and deposited along the coast (Figs. 3a and 3b). This runoff has reduced Nickol Bay to shallow mud flats. Areas of high terrestrial sediment deposition may thus be intermingled within a largely carbonate producing ecosystem. Widespread occurrence of sheet runoff is also common.

It is unlikely that much of the quartz present is biogenic as silica-producing organisms tend to occur in cooler, deeper waters where the fugacity of CO_2 interfers with the production of carbonates (Riley and Chester, 1971).

Other sources such as aeolian deposits may also play a part. Easterly winds which blow throughout the summer months generate dust storms which transport terrestrial sediments to the waters of the study area.

Localised input of silicates is also likely to arise from iron-ore operations where dust from stockpiles and waste from pelletizing plants and washing processes are heavily laden with silica-rich materials.

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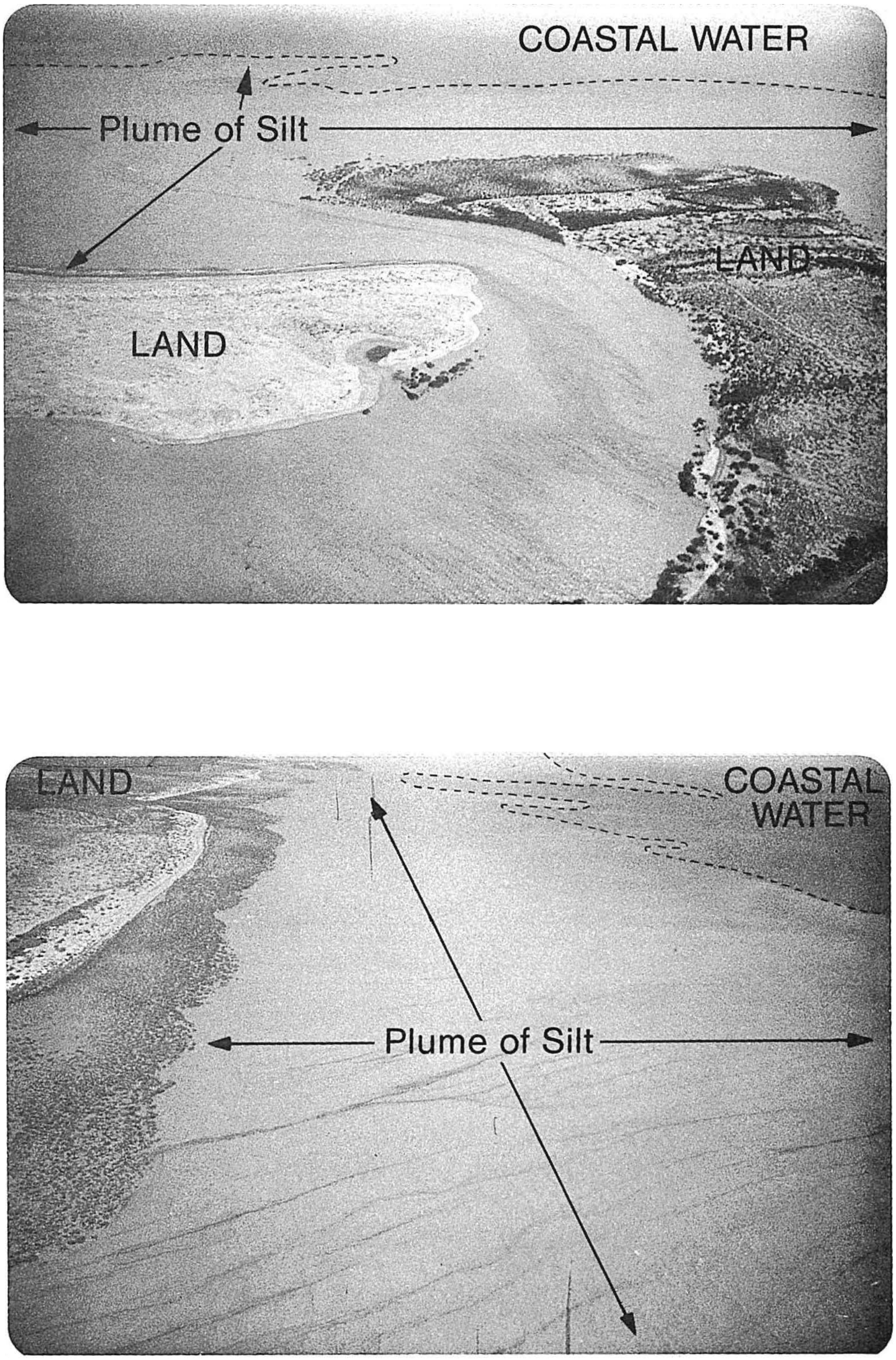

Figs. 3a and 3b. Freshwater laden with silt entering the marine system of the Dampier region after heavy rain. Areas shown are approximately 2km^2 and 3km^2 respectively. Photographs: C. Nicholson.

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Appendix 1

Upper and lower percentile values

Mineral		High Values	Low Values
Quartz	Q	30.5	3.2
Aragonite	A	24.6	3.2
Calcite	C	39.2	22.3
Mg-High Calcite	Mg-C	44.3	17.5
Clays	CL	2.5	0.01
Feldspars	F	2.00	0.01
Total Carbonates	TC	96.7	63.5
	C+Mg-C/A	6.5	2.1
	C/A	3.2	1.1
	Mg-C/A	3.3	0.9
	C/Mg-C	1.7	0.9
	C+A/Mg-C	2.4	1.0
	TC/Q	29.3	1.9
	TC/Silicate	29.1	1.7
	A/Mg-C	1.2	

Appendix 2

Mineralogical composition (%) of sediiments collected at sites 1-85 in the Dampier region and ratios of selected groups of these minerals.

Site	%Quartz	%Aragonite	%Calcite	%Mg-high Calcite	%Clays	%Feldspars	%Total Carbonates								
	Q	A	C	Mg-C	CL	F	TC	$\frac{C+Mg-C}{A}$	$\frac{C}{A}$	$\frac{Mg-C}{A}$	$\frac{C}{Mg-C}$	$\frac{C+A}{Mg-C}$	$\frac{TC}{Q}$	$\frac{TC}{Silicate}$	$\frac{A}{Mg-C}$
1	15.0	17.3	25.7	42.0	0.01	0.01	85.1	3.9	1.5	2.4	0.6	1.0	5.7	5.7	0.4
2	14.1	18.2	26.4	41.3	0.01	0.01	85.9	3.7	1.5	2.3	0.6	1.1	6.1	6.1	0.4
3	8.8	10.8	35.0	40.9	3.50	1.00	90.1	6.6	3.0	3.6	0.9	1.1	9.9	6.5	0.3
4	18.4	15.0	27.3	34.0	3.00	2.30	78.3	4.1	1.8	2.3	0.8	1.2	4.1	3.2	0.4
5	36.7	7.8	22.3	16.0	3.20	13.00	46.1	4.9	2.9	2.1	1.4	1.9	1.3	0.9	0.5
6	19.5	15.0	19.4	44.1	1.00	1.00	78.5	4.2	1.3	2.9	4.4	0.8	4.0	3.7	0.3
7	16.9	12.7	31.9	32.3	3.90	3.30	76.9	5.1	2.5	2.5	1.0	1.4	4.6	4.6	0.4
8	11.7	33.0	37.1	16.3	1.40	0.50	86.7	1.6	1.1	0.5	2.3	4.3	7.4	6.4	2.0
9	20.4	16.2	30.1	30.3	2.00	1.00	85.5	2.7	1.3	1.4	0.9	1.6	2.3	3.3	0.5
10	06.7	34.4	26.4	28.0	3.50	1.00	90.6	1.6	0.8	0.8	0.9	2.1	13.2	7.9	1.2
11	30.5	7.5	27.2	30.7	3.70	0.40	65.4	7.7	3.6	4.1	0.9	1.1	2.1	1.9	0.2
12	29.9	6.9	32.9	26.3	1.50	2.50	66.1	8.6	4.8	3.8	1.3	1.5	2.2	1.9	0.3
13	34.7	13.2	28.0	17.5	1.00	5.60	58.7	3.5	2.1	1.3	1.6	2.4	1.7	1.4	0.8
14	28.7	14.4	35.7	15.7	2.50	3.00	61.8	4.0	2.8	1.2	2.4	3.2	2.3	1.9	0.9
15	28.0	9.2	27.1	31.2	2.50	2.00	69.3	6.5	3.0	3.5	0.9	1.2	2.4	2.1	0.3

16	24.2	22.4	29.5	21.9	1.00	1.00	75.8	2.2	1.3	1.0	1.3	2.3	3.0	2.8	1.0
17	9.3	27.7	29.6	31.8	1.00	1.00	89.7	2.2	1.1	1.2	0.9	1.8	9.5	7.9	0.9
18	45.0	07.0	17.1	10.8	1.00	19.10	34.9	4.0	2.4	1.5	1.6	2.2	0.8	0.5	0.6
19	11.5	22.3	40.5	16.2	1.00	8.60	81.9	2.5	1.8	0.7	2.6	4.0	6.9	3.7	1.4
20	29.6	15.8	31.4	19.7	2.30	1.20	66.9	3.2	2.0	1.2	1.6	2.4	2.3	2.0	0.8
21	30.5	12.1	30.3	25.2	1.50	0.40	68.6	4.7	2.5	2.2	1.2	1.6	2.2	2.1	0.5
22	20.2	10.9	41.3	25.1	1.50	1.00	90.7	6.3	3.9	2.4	1.6	2.0	3.8	4.0	0.4
23	22.5	6.3	54.0	14.5	1.70	1.00	77.5	11.3	9.0	2.3	3.9	4.3	3.3	3.1	0.4
24	33.8	24.6	32.0	13.3	2.00	4.30	59.9	1.4	0.9	0.5	1.6	3.5	1.8	1.5	1.8
25	67.0	3.2	4.0	1.0	2.20	22.60	8.2	1.6	1.3	0.3	4.0	7.2	0.1	0.1	3.2
26	26.1	11.0	25.4	31.2	0.90	5.40	67.6	5.2	2.3	2.8	0.8	1.2	2.5	2.1	0.4
27	12.9	22.2	38.0	22.9	3.00	1.00	84.7	2.8	1.7	1.1	1.6	2.5	6.4	5.0	1.0
28	18.9	13.8	32.4	31.6	2.00	1.10	80.1	4.8	2.4	2.4	1.0	1.4	4.1	3.6	0.4
29	2.7	48.3	14.8	31.6	1.70	0.90	94.7	0.9	0.3	0.6	0.5	2.0	35.0	17.9	1.5
30	17.0	11.4	35.1	31.9	1.00	3.60	79.5	6.0	3.2	2.8	1.1	1.5	4.6	3.7	0.4
31	14.0	21.0	37.3	24.2	2.50	1.00	84.2	3.0	1.9	1.2	1.6	2.5	5.7	4.8	0.9
32	3.3	26.0	48.7	20.9	1.00	0.10	96.7	2.7	1.9	0.8	2.4	3.6	28.9	21.9	1.2
33	4.1	27.3	33.7	33.4	1.00	0.50	94.4	2.6	1.2	1.2	1.0	1.8	23.0	16.8	0.8
34	5.8	31.6	27.5	31.8	2.30	1.00	90.9	0.9	1.9	1.0	0.9	1.9	15.7	9.9	1.0
35	4.7	15.2	24.3	53.8	1.00	1.00	94.7	5.2	1.7	3.6	0.5	0.8	19.8	14.1	0.3
36	4.8	34.6	34.4	22.6	1.40	2.20	91.1	1.7	1.0	0.7	1.5	3.0	19.1	10.8	1.5

37	7.8	10.1	35.0	44.3	2.50	0.30	93.7	6.4	3.0	3.5	0.9	1.1	11.5	8.8	0.2
38	1.6	25.2	51.1	21.2	0.50	0.10	98.4	2.9	2.0	0.9	2.4	3.5	60.9	44.7	1.2
39	2.0	14.9	35.7	47.2	0.10	0.10	98.1	5.6	2.4	3.2	0.8	1.1	48.9	44.6	0.3
40	3.4	15.3	34.8	46.3	0.10	0.10	96.6	5.3	2.3	3.0	0.8	1.1	28.4	26.8	0.3
41	12.2	27.9	17.6	42.1	0.10	0.10	87.6	2.1	0.6	1.5	0.4	1.1	7.2	7.1	0.7
42	8.4	15.9	15.8	57.3	1.40	1.10	89.0	4.6	1.0	3.6	0.3	0.6	10.6	8.2	0.3
43	5.8	10.3	31.3	51.5	1.10	0.01	93.1	8.0	3.0	5.0	0.6	0.8	16.0	13.5	0.2
44	10.1	11.9	29.7	44.7	3.20	0.40	87.4	6.2	2.5	3.8	0.7	0.9	8.6	6.4	0.3
45	8.1	14.5	25.0	50.5	0.80	1.10	88.7	5.0	1.9	3.2	0.6	0.9	10.9	8.9	0.3
46	14.8	17.4	26.0	41.8	0.01	0.01	85.1	3.9	1.5	2.4	0.6	1.0	5.8	5.7	0.4
47	6.4	28.5	22.1	43.0	0.01	0.01	93.6	2.3	0.8	1.5	0.5	1.2	14.6	14.6	0.7
48	14.9	24.1	22.3	33.0	3.00	2.70	79.4	2.3	0.9	1.4	0.7	1.4	5.3	3.8	0.7
49	11.1	26.2	16.8	44.1	1.50	0.30	88.6	2.3	0.6	1.6	3.9	1.0	7.9	7.0	0.6
50	16.1	11.5	33.0	36.4	3.00	0.01	81.0	6.0	2.8	3.1	0.9	1.2	5.0	4.2	0.3
51	7.9	15.0	29.7	47.4	0.01	0.01	92.2	5.2	2.0	3.2	0.6	1.0	11.7	11.6	0.3
52	0.9	18.8	38.3	42.0	0.01	0.01	99.1	4.3	2.1	2.2	1.0	1.4	110.1	107.7	0.4
53	4.9	10.4	36.0	48.7	0.01	0.01	95.1	8.1	3.5	4.7	0.7	1.0	19.4	19.3	0.2
54	1.2	12.4	39.1	47.3	0.01	0.01	98.8	7.0	3.2	3.8	0.8	1.1	82.3	80.9	0.3
55	2.1	19.3	26.4	52.2	0.01	0.01	98.3	4.1	1.4	2.7	0.5	0.9	46.8	46.4	0.4
56	3.5	36.5	18.0	42.0	0.01	0.01	96.5	1.6	0.5	1.1	0.5	1.3	27.6	27.4	0.9
57	2.2	18.1	42.0	37.7	0.01	0.01	97.8	4.4	2.3	2.1	1.1	1.6	44.4	44.0	0.5

58	1.0	47.7	28.6	22.7	0.01	0.01	99.2	1.1	0.6	0.5	1.3	3.4	99.2	97.2	2.1
59	1.4	14.1	39.6	43.9	0.05	0.05	98.6	6.0	2.9	3.1	0.9	1.3	70.4	69.9	0.3
60	8.3	17.1	35.2	39.4	0.01	0.01	91.7	4.4	2.1	2.3	0.9	1.3	11.0	11.0	0.4
61	3.3	11.2	53.8	31.7	0.01	0.01	96.7	7.6	4.8	2.8	1.7	2.1	29.3	29.1	0.4
62	41.3	11.5	27.5	18.7	0.50	0.50	58.7	4.1	2.4	1.7	1.4	2.0	1.4	1.4	0.5
63	34.3	13.2	29.0	16.5	1.00	6.00	58.7	3.5	2.2	1.3	1.8	2.6	1.7	1.4	0.8
64	52.3	7.7	16.8	16.4	1.00	5.80	40.9	4.3	2.2	2.1	1.0	1.5	0.8	0.7	0.5
65	67.6	3.6	14.0	9.1	0.30	5.40	26.7	6.4	3.9	2.5	1.5	1.9	0.4	0.4	0.4
66	36.5	7.9	27.0	28.6	0.01	0.01	63.5	7.0	3.4	3.6	0.9	1.2	1.7	1.7	0.3
67	3.8	16.1	34.2	45.4	0.50	0.01	96.3	5.0	2.1	2.8	0.8	1.1	25.2	22.3	0.4
68	3.2	10.1	48.2	38.5	0.01	0.01	96.8	8.6	4.8	3.8	1.3	1.5	30.2	30.1	0.3
69	19.0	21.6	38.9	19.5	1.00	0.01	82.4	2.8	1.8	0.9	2.0	3.0	4.0	4.1	1.1
70	23.4	29.3	22.2	23.1	1.00	1.00	75.5	1.6	0.8	0.8	1.0	2.2	3.1	3.0	1.3
71	8.3	8.6	54.4	28.7	0.01	0.01	91.8	9.6	6.3	3.3	1.9	2.2	11.0	11.0	0.3
72	1.2	14.2	44.0	40.6	0.01	0.01	98.8	6.0	3.1	2.9	1.1	1.4	82.3	81.0	0.3
73	3.0	20.6	39.2	36.2	0.01	0.01	97.1	3.7	1.9	1.8	1.1	1.7	32.0	32.2	0.6
74	34.3	22.7	25.3	16.7	0.50	0.50	64.7	1.9	1.1	0.7	1.5	2.9	1.9	1.8	1.4
75	12.3	17.1	41.2	29.4	0.01	0.01	88.7	4.2	2.5	1.7	1.4	2.0	7.1	7.2	0.6
76	5.3	16.0	36.3	40.0	1.80	0.60	92.3	4.8	2.3	2.5	0.9	1.3	17.4	12.0	0.4
77	6.4	15.1	39.7	38.3	0.50	0.50	93.5	5.2	2.6	2.5	1.0	1.4	14.5	13.4	0.4
78	27.2	22.4	28.3	19.8	1.30	0.50	70.5	2.2	1.3	0.9	1.4	2.6	2.5	2.4	1.1

79	49.1	6.3	25.1	18.5	1.00	0.01	49.9	6.9	4.0	2.9	1.4	1.7	1.0	1.0	0.3
80	4.0	12.0	43.9	39.6	0.50	0.01	95.0	6.9	3.7	3.3	1.1	1.4	23.9	21.1	0.3
81	2.3	11.1	56.7	29.9	0.01	0.01	97.7	5.1	1.9	2.7	1.9	7.8	42.5	42.1	0.4
82	21.8	22.3	28.8	26.1	1.00	0.01	77.2	2.5	1.3	1.2	1.1	2.0	3.5	3.4	0.8
83	36.9	13.5	28.7	19.9	1.00	0.10	62.8	3.6	1.5	2.2	1.5	2.2	1.7	1.7	0.7
84	49.6	17.6	14.9	15.9	2.00	1.00	48.6	1.7	0.8	0.9	0.9	2.1	1.0	0.9	1.1
85	47.9	9.8	19.1	13.3	1.00	8.90	42.9	3.2	1.9	1.4	1.4	2.1	0.9	0.7	0.7