THE GEOLOGY OF WARDANG ISLAND,

YORKE PENINSULA, SOUTH AUSTRALIA

by

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Frontispiece : Aerial Views of Wardang Island looking to the south, east and north.

ABSTRACT

The crystalline Basement consists of porphyritic rhyo-dacite, with minor latite, conglomerates and metasediments. Geochemistry indicates possible affinities with the Gawler Range Volcanics and the Moonta Porphyry. The sequence is intruded by amphibolite dykes. Metamorphic and tectonic events have modified the rocks, destroying primary textures. These events may be related to the Olarian orogeny. The figure of 1735 m.y. obtained on the rhyo-dacite probably represents a re-setting event.

Permian glacigene sediments unconformably overlie the acid volcanics. These sediments consist of mottled clays and quartz arenites, and contain heavy mineral grains the surfaces of which show well-defined chattermark trails. Erratics are numerous. Grooved bedrock surfaces indicate a 340^{o} ice movement direction, as does the Cape Willoughby source for the largest granite erratic.

A richly-fossiliferous Pliocene sequence - the Hallett Cove Sandstone - overlies the Permian and the Basement. The 4 m thick sequence shows ten distinct horizons, reflecting differing environmental conditions.

The Quaternary cover shows evidence of Holocene sea-level changes in the form of stranded shingle beach ridges, aeolianite wave-cut platforms and undersea calcrete reefs. These also record palaeoclimatic changes, as do the fossil soils, calcretes and aeolianite dunes. The geochemistry of the calcretes reflects that of the underlying bedrock, and places constraints on the calcrete-formation model postulated.

A salt-marsh-prograding barrier beach couplet shows the classic features of such an environment. Palaeontological analyses of the Recent sands indicates a diverse death assemblage, the dominance differences probably resulting from life-assemblage environmental differences, particularly depth and bottom. The presence of *Marginopera vertebralis* in the tidal

detritus between Wardang Island and Goose Island indicates that this species may still be extant in this locality. $MgCO_3$ analyses support this hypothesis.

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INTRODUCTION

Wardang Island is a small (approximately 20 km^2) off-shore island in Spencer Gulf. It is 8 kms west of Port Victoria, which is 195 road kms from Adelaide. The topography is subdued, with the highest point 30 m above sea level. Vegetation is predominantly low shrubland and grasses, with Chenopodiacae the most well represented family. The low trees *Olearia axillaris* has colonised the sandier areas, whilst *Arthrocnemum arbuscula* occurs in the Mangrove zone.

The Island is presently being developed as an Outdoor Educational Resource Area by the Department of Further Education. Although previous work has been carried out on the area, the aim of the project was to produce a reference work suitable for the various academic levels of the potential users of the area. Already, groups ranging from Kindergarten to University level have visited the Island, indicating the need for a comprehensive Field Guide, also containing unresolved problems to provide stimulation and enquiry. Early field mapping established a new stratigraphic sequence to that which existed, namely Precambrian, Permian, Pliocene and Quaternary. Each of these sequences was studied in detail, with field work supported by the study of thin sections, hand specimens, geochemical analyses, S.E.M. photography, photomicrographs and field photography.

WARDANG ISLAND

SAMPLE LOCATION MAP

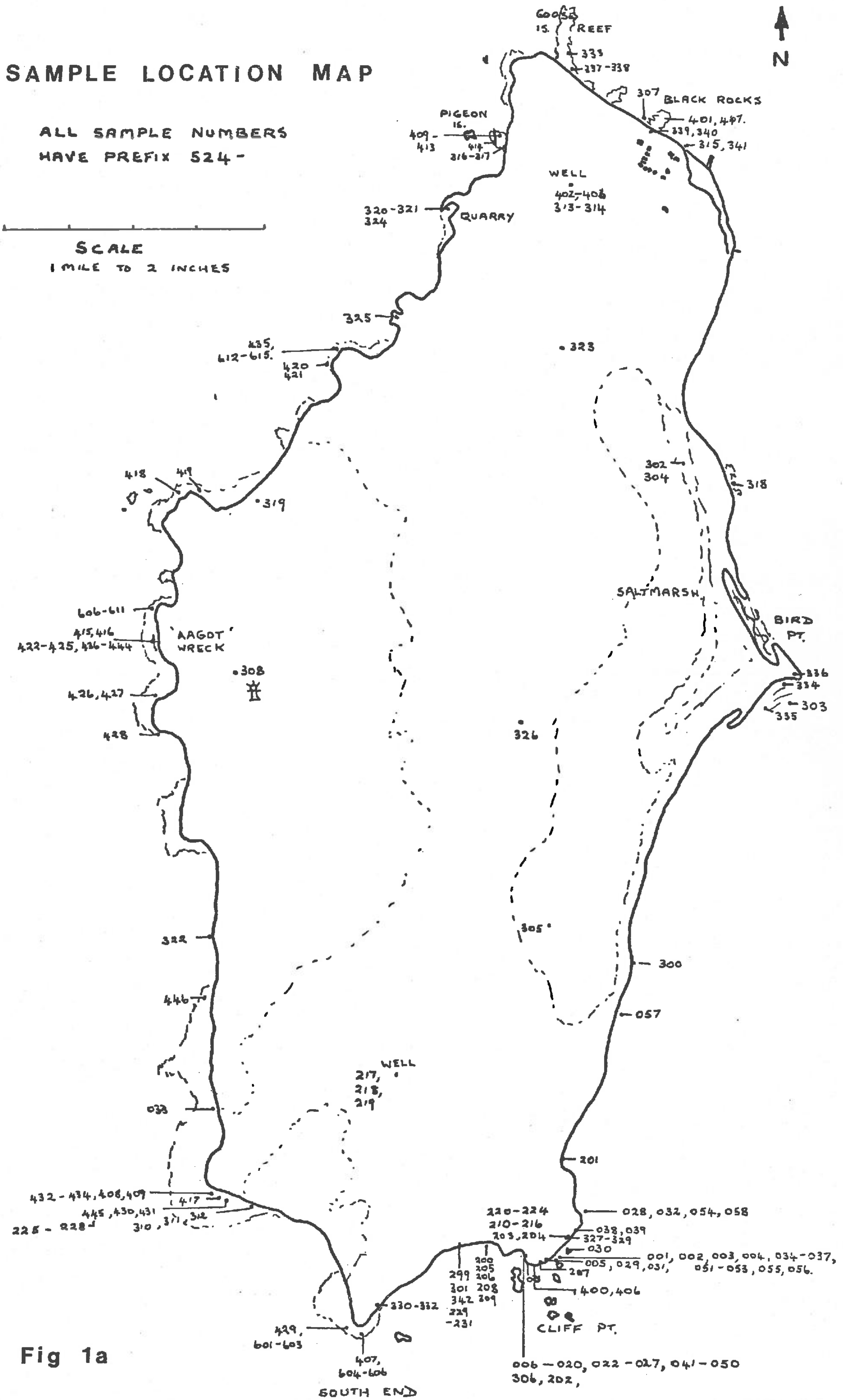


Fig 1a

PRECAMBRIAN CRYSTALLINE BASEMENT

The present study has shown that the Basement rocks consist of metamorphosed volcanics of the andesitic suite (Joplin, 1964) and not granite gneiss and paragneiss as formerly proposed (Crawford 1965, and Buckhorn 1974). Its distribution is shown in Fig. 1. It is a dark pink-grey prominently jointed porphyry (Plate 1) which on weathering superficially resembles gneiss. This resemblance is enhanced by the development of a veined stictolithic structure due to hornblende/biotite segregation, derived from the adjacent zone (524-423).

Conglomerates and metasediments are interbedded in the volcanics at the Aagot wreck location (Fig. 1, Location A). The conglomerate contains rounded clasts of rhyo-dacite in a latite-derived matrix. The latite was also the metasediment source. The metasediment-volcanic contact is quite sharp (Plate 1), with larger clasts in troughs and thinning of clasts over crests. Clastic feldspar grains derived directly from the weathering of the porphyry are common in the metasediments.

Amphibolite dykes, averaging 10 m in width, intrude the volcanics on the western coast, striking 342° (Plate 5).

Petrography

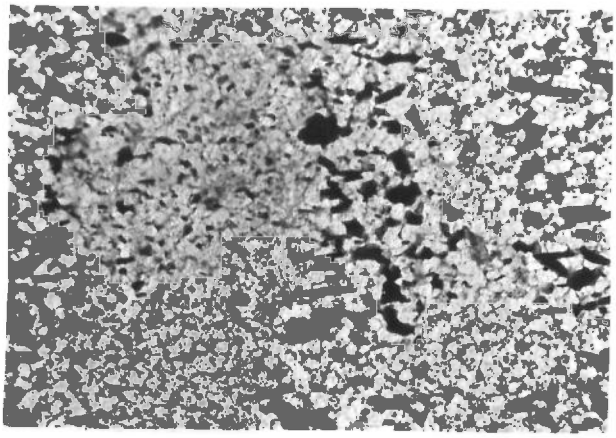
The mineralogy consists of 2 phases - phenocrysts and matrix. The phenocrysts are $\leqslant$ 2 mm calcic-plagioclase(An_{45-60}), usually sericitised, with inclusions of carbonate, scapolite and chlorite (Plate 1). The fine-grained, recrystallized matrix of the rhyo-dacite consists predominantly of K-feldspar, plus quartz, plagioclase, biotite, opaques (ilmenite and magnetite) ± hornblende and epidote ± accessory zircon, apatite, carbonate and scapolite. The matrix of the latite is similar, but with less quartz and K-feldspar and more mafic minerals. Triple-point junctions substantiate the high-grade metamorphic recrystallization event, which obliterated primary textures. Although relict shards are not indisputably present, this rock was probably originally an ignimbrite of the ash flow type. The

PLATE 1

PRECAMBRIAN CRYSTALLINE BASEMENT

1. 524-443 Metasediment. Tectonic fabric shown by biotite- orthogonal to bedding. Plane light. Location A (Fig. 1) x 30.
2. 524-409 Porphyritic rhyo-dacite, showing plagioclase phenocrysts in fine grained matrix. Crossed-polars. Location F (Fig. 1) x 17.
3. 524-409 Porphyritic rhyo-dacite. Biotite and chlorite wrapped around sericitised phenocrysts. Pressure shadow re-crystallization developed. Plane light. Location F (Fig. 1) x 17.
4. Conglomerate and metasediment contact, with clast elongation orthogonal to bedding. Location A (Fig. 1).
5. Joints in porphyritic rhyo-dacite. Location B (Fig. 1).
6. Conglomerate. Rhyo-dacite clasts in latite-derived matrix. Location A (Fig. 1).
7. Trough and crest on conglomerate - metasediment contact. Location A (Fig. 1).

PLATE 1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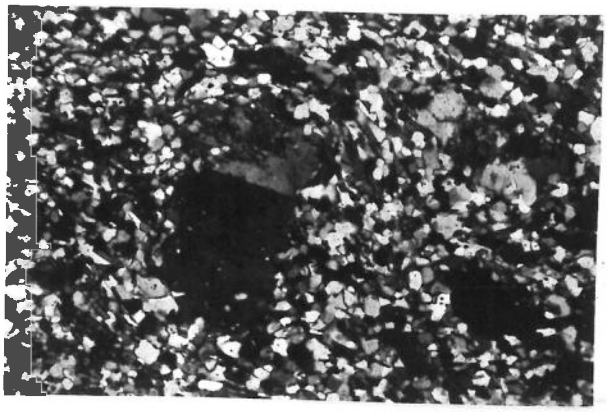
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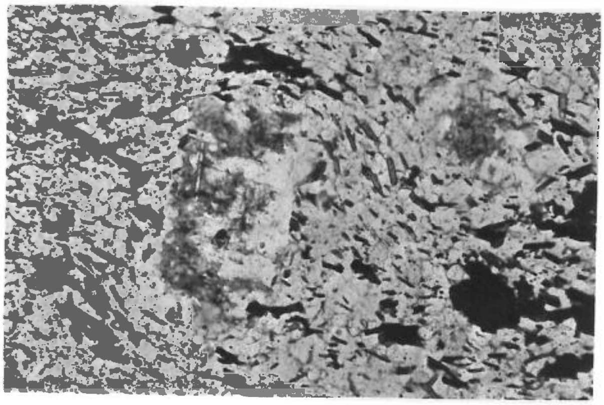
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random orientation of the more elongate phenocrysts, poor sorting and lack of graded beds discount the possibility of an air-fall origin. Lemar (1975) refers to analogous material (3361 and 3366) as rhyolite-tuff-breccia. Staining (Appendix 2) confirmed that the matrix consists predominantly of K-feldspar rather than quartz and that none of the phenocrysts are K-feldspar.

The dykes consist of recrystallised, coarse-grained green amphiboles, with minor amounts of plagioclase and opaques ± epidote .

Hand specimen and thin section descriptions are recorded in Appendix I.

Geochemistry

Analyses are tabulated in Table 1 and compared with an estimated average upper crustal composition (U.C.) (Taylor, 1976), the Moonta Porphyry (Lemar, 1975), the Gawler Range Volcanics (Giles, 1978) and the Roopena Volcanics (Horr, 1977). Methods appear in Appendix 3.

The homogeneous porphyries have the chemistry of the calc-alkaline suite (Pichler and Ziel, 1968), in particular of a rhyo-dacite and minor latite, but are relatively 'basic' for their high SiO_2%. There are subtle differences between them and the Gawler Range Volcanics - higher CaO (probably reflecting more ca rich plagioclase), TiO_2, FeO and MgO. They have relatively higher Nb and Y, but these elements could be in the TiO_2. Zr is comparable, but both contain zircon in their mode. It is more difficult to compare them with the variable Moonta Porphyry, although there is an overall similarity, apart from higher CaO and K_2O and consequent trace element differences, e.g. Rb.

The K-Fe metasomatism that has been documented for the Moonta Porphyry and Roopena Volcanics (Fig.11) probably also affected the Wardang Island volcanics - maybe even more so, due to an increasing grade of metamorphism being apparent as one moves south down Yorke Peninsula.

Geochemically they are similar to the Eyre Peninsula acid charnockites (Mortimer, pers. comm.) but with lower Sr, i.e. could be the same parental source.

MAJOR TRACE ELEMENT ANALYSES

	524-601	524-602	524-603	524-604	524-605	524-606	524-607	524-608	524-609	524-610	524-611	524-612	524-613	524-614	524-615	524-620
SiO_2	68.74	69.64	69.24	68.56	69.35	68.87	70.53	72.04	70.04	69.65	70.35	69.74	69.09	69.68	69.62	74.60
Al_2O_3	12.61	12.58	12.59	12.55	12.70	12.39	12.84	12.39	12.53	12.45	12.71	12.05	12.67	12.00	12.62	11.76
Fe_2O_3	5.60	5.66	5.59	5.53	5.64	5.48	5.01	2.93	4.82	4.84	4.78	5.10	5.27	5.19	5.06	3.02
MnO	0.06	0.08	0.09	0.06	0.06	0.06	0.05	0.02	0.02	0.03	0.02	0.04	0.03	0.02	0.03	0.01
MgO	0.74	0.83	0.75	0.75	0.90	0.82	1.11	0.39	0.71	1.10	0.75	0.34	0.95	0.82	0.69	1.44
CaO	2.17	2.24	2.39	2.22	2.19	2.13	1.55	1.74	1.56	1.60	1.50	2.29	1.84	1.80	1.71	0.43
Na_2O	3.13	2.81	3.13	3.11	3.01	3.16	2.92	3.34	2.98	3.00	3.26	3.24	3.21	3.13	3.40	5.85
K_2O	4.33	4.67	4.73	4.53	4.47	4.61	5.05	4.81	5.23	4.99	5.02	4.59	4.72	4.72	4.85	0.56
TiO_2	0.73	0.73	0.74	0.72	0.72	0.72	0.74	0.74	0.74	0.72	0.73	0.70	0.73	0.73	0.73	0.43
P_2O_5	0.17	0.17	0.17	0.18	0.16	0.18	0.18	0.18	0.17	0.18	0.18	0.17	0.18	0.17	0.18	0.07
H_2O (loss)	1.51	0.70	0.80	1.43	1.37	1.52	0.61	1.04	0.76	0.76	0.94	1.26	1.01	0.87	0.98	1.12
Total	99.70	99.41	100.22	99.64	99.22	100.14	99.97	99.60	99.56	99.33	100.24	99.52	99.70	99.18	99.87	99.28
Zr	515	501	530	527	509	497	518	529	525	526	547	521	526	511	521	528
Nb	38	38	41	42	30	42	38	42	40	39	41	42	44	38	42	54
Rb	187	224	219	228	217	227	198	162	188	172	187	178	205	198	217	21
Sr	78	92	97	85	81	84	97	105	99	89	97	91	130	121	118	21
Y	71	74	74	74	71	72	71	702	70	59	76	70	69	72	72	95
Th		27			30		26							30		
Ba	719	748	712	718	754	742	899	949	880	869	838	742	863	962	913	56
Sc		11			11		11							11		
Ti	4055	4146	4131	4040	3972	4034	3979	3878	3875	3898	3935	3864	3978	3959	3972	2507
Ce	175	171	169	175		163		229	159	160	182	171	144		162	698
Nd	77	87	91	88		87		107	81	73	85	81	67		77	361

	GV1	GV2	3361	3366	U.C.	524-439	524-440	524-442	524-443	524-417	SAS 1 - SAU 3 075	085	095
SiO_2	66.08	70.72	69.20	73.90	66.00	68.26	54.60	66.48	58.88	47.85	50.22	49.55	49.61
Al_2O_3	13.83	13.80	12.50	13.10	16.00	14.44	20.41	13.38	17.93	14.34	14.05	13.92	13.31
Fe_2O_3	5.77	3.40	3.92	2.65	4.50	4.81	6.98	6.17	6.66	13.93	12.83	14.88	12.37
MnO	0.13	0.06	0.04	0.01	-	0.06	0.09	0.15	0.08	0.22	0.22	0.21	0.24
MgO	0.62	0.50	1.70	0.65	2.30	1.14	1.62	1.81	2.33	7.25	8.13	7.84	10.27
CaO	2.67	0.37	0.49	0.32	3.50	2.54	4.07	5.46	2.59	9.47	7.53	6.03	7.81
Na_2O	3.43	3.64	4.20	6.50	3.80	3.58	5.19	2.54	3.75	2.15	4.12	4.36	3.63
K_2O	4.61	6.07	2.40	0.37	3.30	3.93	4.69	2.26	6.17	1.58	1.19	1.31	1.38
TiO_2	0.82	0.44	0.89	0.06	0.60	0.38	0.98	0.67	0.73	1.46	1.56	1.74	1.25
P_2O_5	0.21	0.05	0.08	0.65		0.06	0.23	0.16	0.18	0.18	0.15	0.16	0.12
H_2O (loss)	1.43	0.92	1.80	1.09		0.78	0.69	0.71	0.87	1.57			
Total	99.60	99.97	100.10	100.05	100.00	99.98	99.55	99.79	100.17	100.00			
Zr	401	654				212	666	480	666	85	85	100	78
Nb	20	20				18	50	39	24	7	6	8	5
Rb	188	174				215	331	191	525	136	46	42	50
Sr	187	49				197	211	122	222	142	181	189	174
Y	48	49				90	94	73	86	27	23	29	22
Th													
Ba	1215	1170				878	627	455	1019	331	118	66	566
Sc	13	11											
Ti	4916	3000				2154	5311	3884	4192	8001			
Ce						288	250	182	296	31			
Nd						129	111	76	132	17			

TABLE 1

SELECTED RATIOS

	524-601	524-602	524-603	524-604	524-605	524-606	524-607	524-608	524-609	524-610	524-611	524-612	524-613	524-614	524-615	524-620	GV1	GV2	3361	3366	U.C.	524-439	524-440	524-442	524-443
Rb/Sr	2.40	2.43	2.26	2.68	2.68	2.70	2.04	1.54	1.90	1.93	1.93	1.96	1.88	1.64	1.84	1.00						1.09	1.57	1.57	2.36
K/Rb	192	173	179	165	171	169	211	248	231	241	244	214	191	198	186	221						152	118	98	98

U.C. = Average composition of the upper crust (Taylor, 1976).
524-620 = Moonta Porphyry
G.R.V 1 & 2 = Gawler Range Volcanics (Giles, 1978)
3361 & 3366 = Moonta Porphyry (Lemar, 1975)
SAS1 & SAU3 = Roopena Volcanics (Hörr, 1977)

Wardang Island
524-601 to 524-615 rhyo-dacite (porphyry)
524 - 439 conglomerate with mafic matrix
524 - 440 latite
524 - 442 metasediment with porphyry clasts
524 - 443 metasediment
524 - 417 amphibolite dyke

TABLE 2

Ab-An-Or and SiO_2-Or-Ab plots (Figs. 2 and 2a), support the probable correlation between the Wardang Island and Gawler Range acid volcanics moreso than the Moonta Porphyry, although it is likely that they are all part of the same province.

Analyses of samples from the Aagot site confirm the field evidence for a short hiatus in volcanism and the subsequent deposition of a relatively thin locally derived sedimentary sequence, younging to the south (Fig. 4). The analyses also preclude the likelihood of a western derivation of the sediments as suggested by Buckhorn (1974) as the low normative SiO_2 and high Ce, Nd and Y values are inconsistent with values in possible Eyre Peninsula source rocks (Mortimer, pers. comm.). The conglomerate consists of clasts of rhyo-dacite and minor latite in a matrix derived predominantly from the underlying latite (Plate 1). The Ab-An-Or and SiO_2-Or-Ab plots (Fig. 2 and 2a) support this model, as does the theoretical plot, in lieu of Rare Earth Elements, of Ce, Nd and Y normalised to chondrite abundances (Fig. 5).

The enrichment in Ce, Nd and Y, low K/Rb ratios and high Rb/Sr ratios (Table 2) suggest that the parental magma resulted from fractional crystallization. However, zircon has a large Kd for R.E.E. and could be the cause of the high values and not fractional crystallization (Hanson, 1976). Opposing this, the very low $^{87}Sr/^{86}Sr$ ratios (Table 3) suggests a mantle origin, but the total Sr content again negates this. So, overall the trace-element data are consistent with the magma being derived by a two or more multistage process from a primitive mantle (Taylor, 1969) but more work is needed, in particular Ni, Co, Cr and V data.

Geochronology

As the petrography and geochemistry enable correlation of the Wardang Island volcanics with the Gawler Range volcanics and Moonta porphyry, radiometric dating was undertaken to determine whether they were also of the same age. The initial $^{87}Sr/^{86}Sr$ ratio obtained would also be useful in placing constraints on the origin of the volcanics (Hyndman, 1972).

NORMATIVE PLOTS

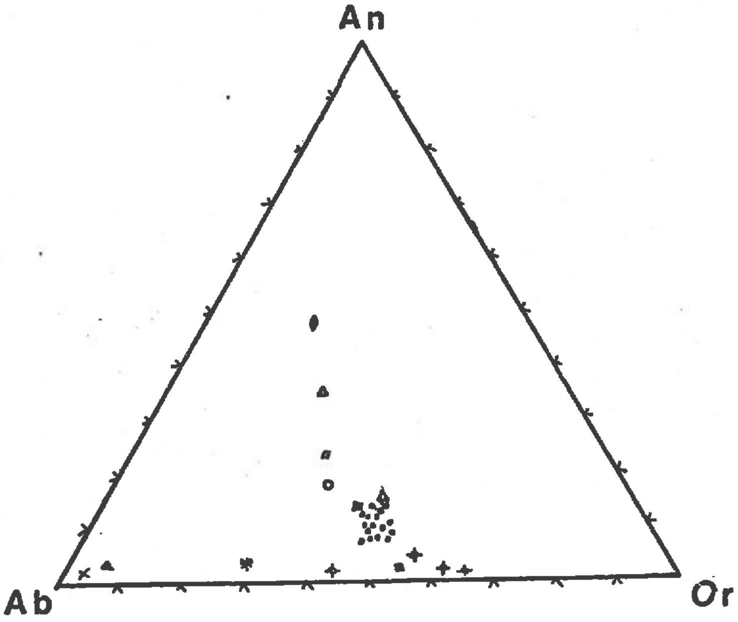


Fig 2

- • PORPHYRITIC RHYO-DACITE
- o 524-439
- ▫ 524-440
- △ 524-442
- 0 524-443
- ♦ DYKE - 524-417
- ▲ MOONTA PORPHYRY (524-620)
- * MOONTA - 3361
- + MOONTA - 3366
- ✚ MOONTA
- ■ GAWLER RANGE VOLCANICS

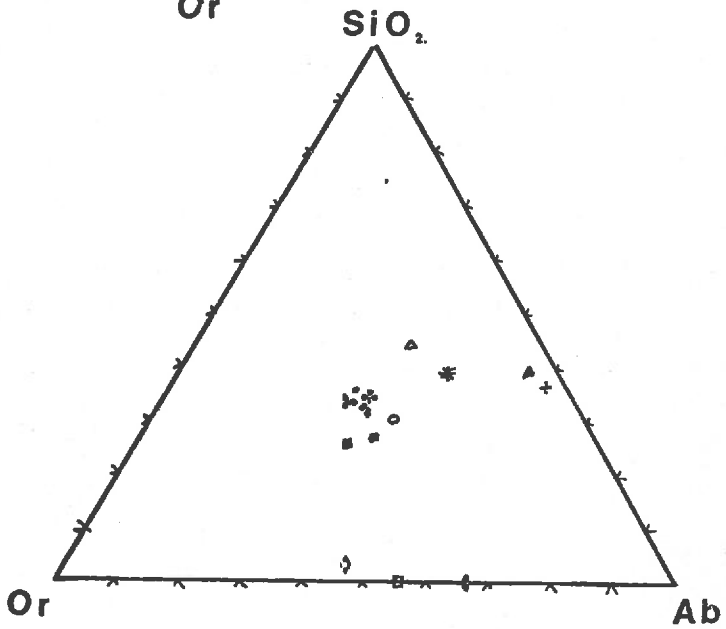


Fig 2a

TERNARY DIAG.

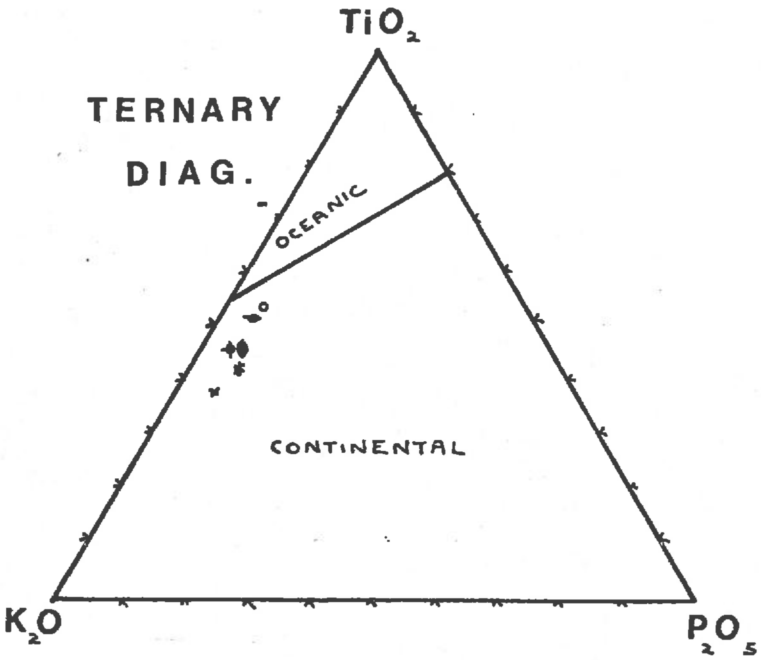


Fig 3

- ♦ DYKE 524-417
- × 86 (PEDLAR)
- * 87 (PEDLAR)
- o 075 SAS1 & SAS3 (HÖRR)
- -o- 085 SAS1 & SAS3 (HÖRR)
- -♦- 095 SAS1 & SAS3 (HÖRR)

SECTION

MEASURED

AT

'AAGOT'

LOCATION

PRECAMBRIAN

ACID VOLCANICS

& METASEDIMENTS

SCALE

1 cm : 3 m.

YOUNGING

TO SOUTH ↑

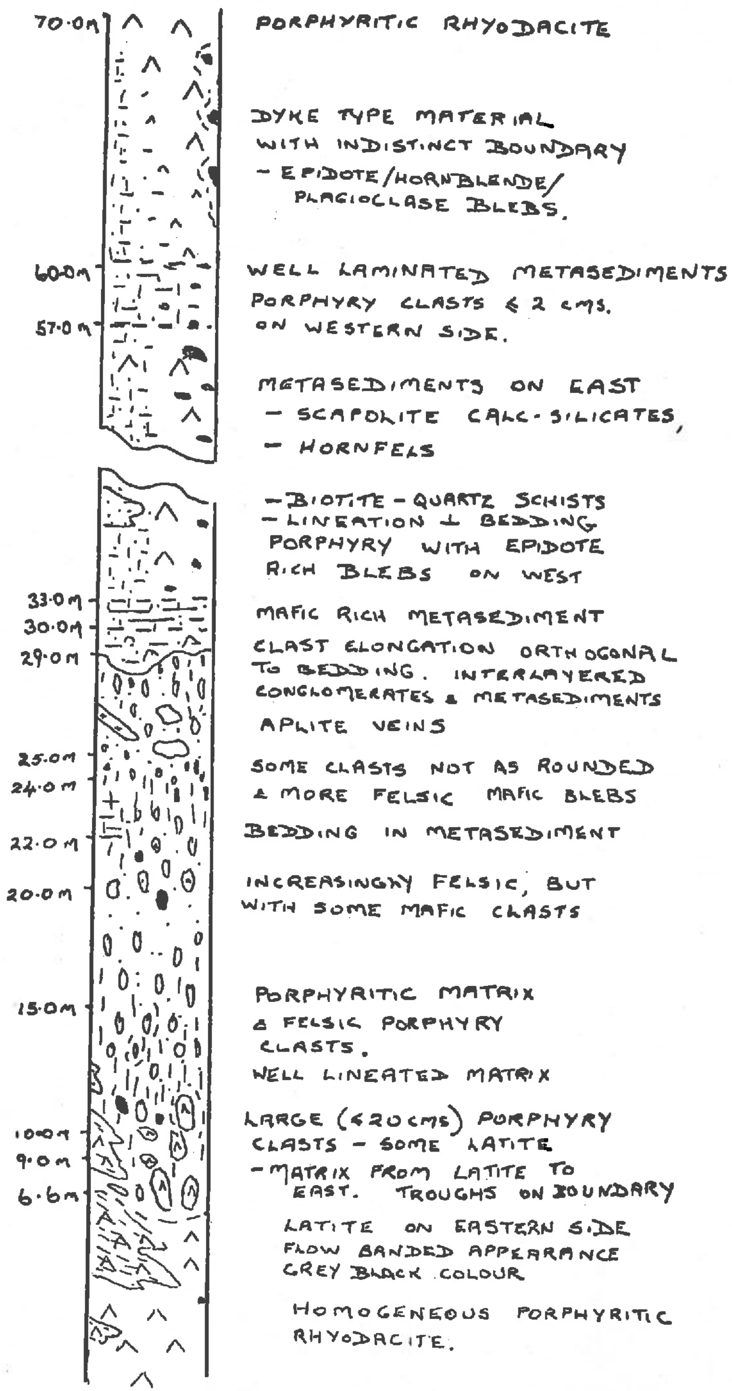


Fig 4

Ce, Nd, Y PLOT

NORMALISED TO CHONDRITE ABUNDANCES.

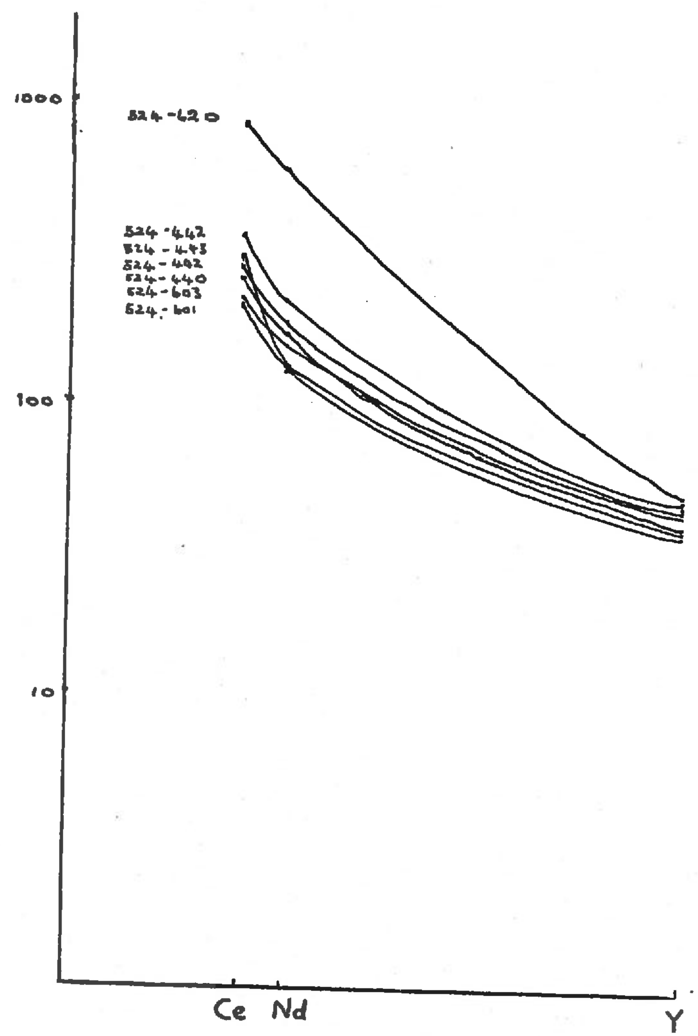


Fig 5

15 samples, weighing approximately 3 kgs each were collected from 4 locations (Fig. 1, Locations B-E). All samples were analysed for Rb/Sr and the 10 which produced the best range were used. Analytical work was performed by M. Fanning, using the Rb-Sr dating technique of Cooper et al. (1978).

The results of Rb/Sr and Sr isotope analyses are tabulated in Table 3 and graphically represented in Fig. 6. Estimates of analytical precision are included in Table 3, and ages are quoted relative to $\lambda^{87}Rb = 1.42 \times 10^{-11} yr^{-1}$. The regression of all 10 samples yields a scatter not greatly in excess of that attributable to experimental error. However, the initial ratio is too low (0.698 ± .008) even for a magma derived from the mantle.

The scatter and low I.R. may be attributable to samples 524-607 and 524-611, which clearly do not fit a line of best fit. Regression of the remaining 8 samples gives quite a good isochron (M.S.W.D. = 1.42), with an I.R. above the minimum geologically accepted value. However, the I.R. is probably still too low at 0.701 ± .004, particularly taking the 2σ error into account. The upper limit of 0.705 is comparable to the Gawler Range value of 0.706, obtained by Webb, (1977) and Compston et al. (1966), whilst the age calculated, 1735 m.y., is considerably older than the previous authors' 1535 m.y. age determination.

Although differentiation into 2 distinct groups cannot be made from the hand specimens, separation on field evidence places 524-601 to 524-606 localities to the east of a 'shear' zone (Fig. 1, Location F), whereas 524-607 - 524-615 localities lie to the west and are intruded by amphibolite dykes. The intrusion of these dykes could have reset these samples, as the volcanics here show numerous epidote veins. Furthermore, the geochemistry indicates that the volcanics young towards the south, contrary to the isotope data, so that reliance should not be placed on the figures produced as indicative of primary crystallization, but rather as an indication of the last re-setting event.

Due to the remobilisation of K, a more reliable figure might be ob-

WARDANG ISLAND RHYO-DACITE

REGRESSION DATA

Regression Group	Samples	Model	MSWD	Initial Ratio	Age M.a.
A. All samples	10	3	8.04	0.698 ± 0.008	1758 ± 91
B. "Older Suite" 601 - 606	6	2	1.02	0.678 ± 0.012	1939 ±115
	5	2	1.34	0.682 ± 0.049	1905 ±453
C. "Retrogressed" 607 - 615	5	3	1.23	0.723 ± 0.010	1423 ±132
D. Without 524-607 & 524-611	8	2	1.42	0.701 ± 0.004	1735 ± 42

TABLE 3

ISOCHRON OF REGRESSION GROUP D.

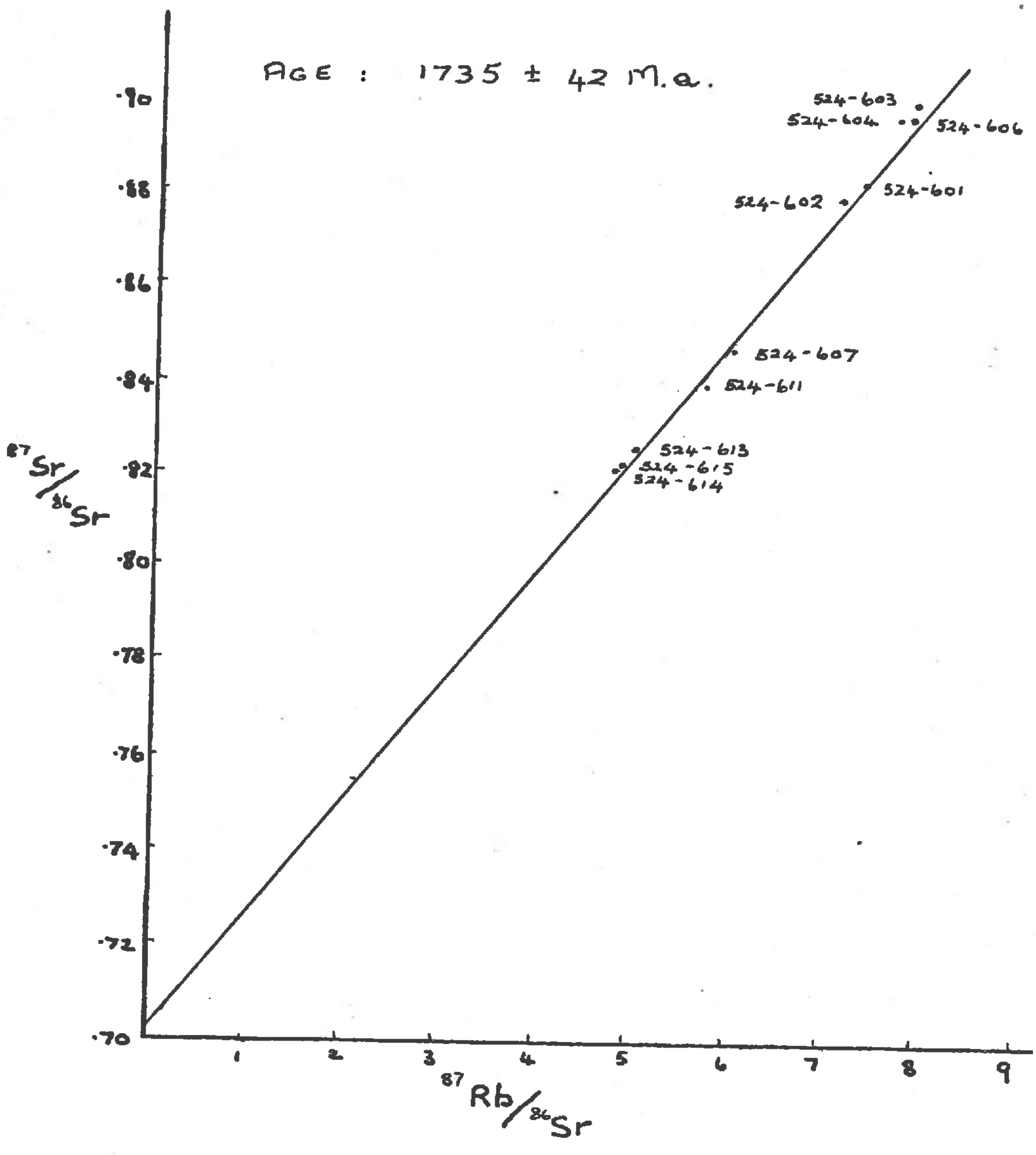


Fig 6

ained using hornblende, although it is doubtful that this is primary.

The low initial ratio does support the theoretical derivation of the acid volcanics from an Archaean tholeiitic source, possibly as a multi-stage process.

Structure

At least two deformation events have affected the volcanics. Rotation and elongation of the rhyo-dacite clasts within the conglomerate (Plate 1) has occurred, so that the clasts are now oriented orthogonally to the bedding plane (Plate 1). Measurements were made of the long and short axes of 150 clasts on 3 joint planes and plotted (Figs. 7, 8, 9). The plots lie within the field of prolate strain. The microfabric shown by the linear secondary biotite wraps around the clasts and the phenocrysts, and is orthogonal to the bedding plane (Plate 1). There is some evidence of a pressure shadow effect at each end of some phenocrysts, although the phenocrysts themselves still exhibit random orientation (Plate 1). This lineation does not penetrate the amphibolite dykes, although secondary linear epidote indicates a second deformation event.

Joint planes were measured at 14 locations, giving 4 well-defined joint sets (Fig. 10). These could not be related to particular events without detailed field laboratory analyses beyond the present scope of the project - as with the conglomerate clasts.

Metamorphism

At least 3 phases of metamorphism have occurred. The first, of amphibolite grade, caused the recrystallization of the vitric matrix of the volcanics and the formation of large grains of biotite, amphibole and scapolite (Plate 1). Considering that metamorphic recrystallization causes an increase in grain size the original grain size of the matrix must have been extremely fine, which further supports the evidence of an extrusive origin for the porphyry. The second event formed small linear biotite grains, and the recrystallization of felsic minerals around some of the phenocrysts (Plate 1).

JOINT PLANES

Strain analysis data

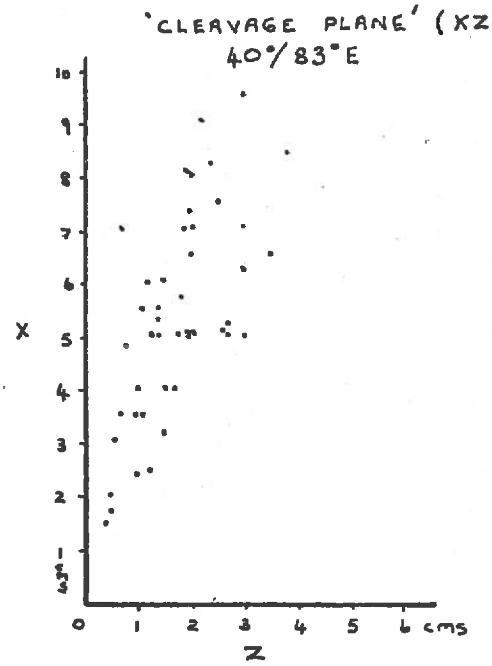


Fig 7

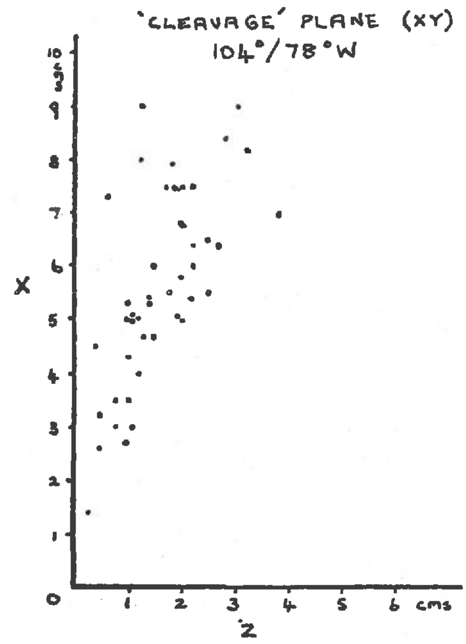


Fig 8

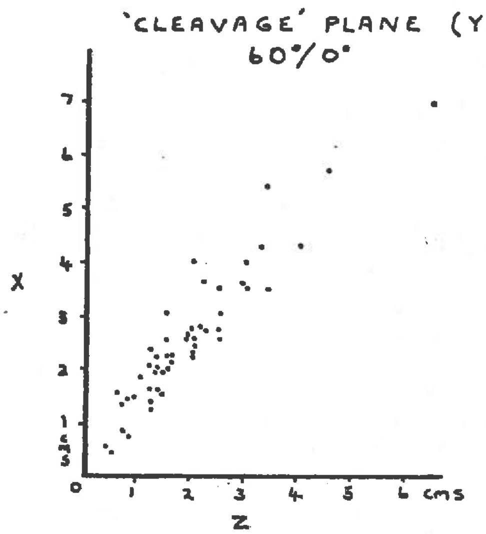


Fig 9

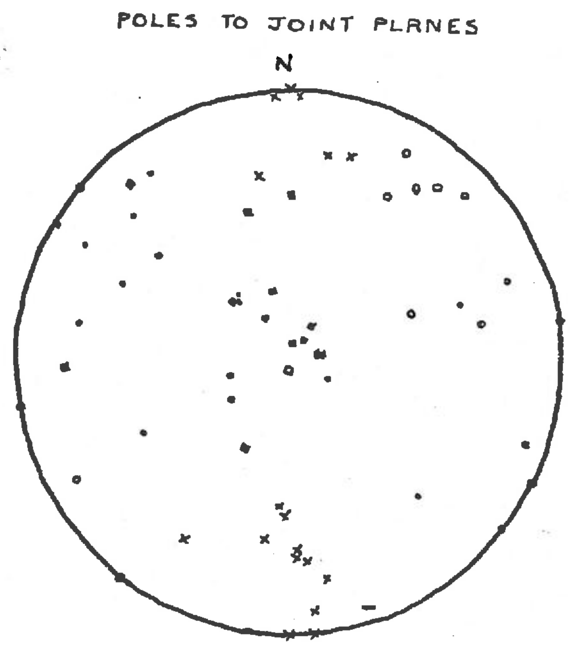


Fig 10

The third event saw the retrograde development of hornblende within the dykes, probably from primary pyroxene. At this stage much of the linear biotite retrogressed to chlorite. Carbonate, scapolite and epidote also formed during this retrograde readjustment (Deer, _et al_. 1974), probably from a more calcic plagioclase than that now present. The K-Fe metasomatism (Mason _et al_. 1978) event occurred after these events, giving higher K_2O and associated trace element values.

These metamorphic and deformation events appear to be analogous to those of the Proterozoic Olarian orogeny discussed by Glen _et al_. (1977).

Amphibolite Dykes

The geochemistry (Table 1) of the dykes is that of a tholeiitic basalt and comparable to the Roopena Volcanics (Hörr 1977), the dykes of southern Yorke Peninsula (Pedlar, 1976) and the Bute amphibolite (Parker & Thomson, 1977), all of which plot in the field of continental tholeiitic basalts on Pearce _et al_'s (1975) TiO_2-P_2O_5-K_2O ternary diagram (Fig. 3). Mason _et al_. (1978) have proposed the dolerite dykes of northern Eyre Peninsula as the "roots of feeders to the Beda volcanics". Although the Wardang Island dykes may have the same source, an age correlation cannot be implied until further work is done.

STRATIGRAPHIC CORRELATIONS

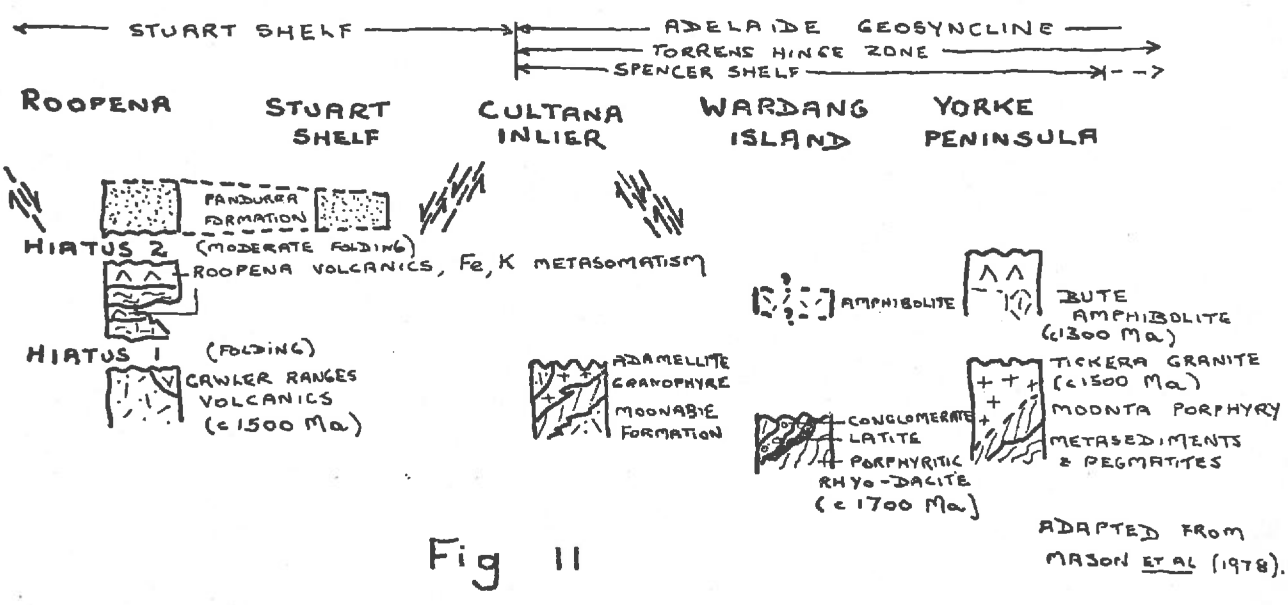


Fig 11

PERMIAN

Previously unrecorded Permian glacigene sediments which include till and pebbly sandstones occur on the south-east coast line (Fig. 1). They unconformably overlie the Basement, which in places shows probable exhumed roche moutonées (Plate 10). The unconformity surface is broadly grooved suggesting a NNW ice movement direction, but there are no definite glacially polished pavements.

The Permian sediments are immature and variable in lithology. On the foreshore (Fig. 1, Location H) an outcrop of unbedded, poorly sorted, indurated quartz arenite contains assorted erratics and limonite pseudomorphs, some still with pyritic cores. Its matrix is highly variable, ranging from ferruginous (Plate 2) to clay-rich to ferroan dolomite (Plate 2), the latter determined by staining (Appendix 6).

Further north, in the cliff face (Fig. 1, Location I) the contact between the Permian and Pliocene is exposed (Plate 3). The glacigene sediments are extremely weathered and have been altered to kaolin, but some ferroan dolomite is still present (524-038). Erratics are common and are re-worked into the basal Pliocene and Recent deposits. As the lowermost Pliocene also contains ferroan dolomite cement, this dolomitization post dates it and is therefore not a Permian event. The time of formation of the authigenic pyrite is also problematical.

Higher in the sequence and to the south and west, the Permian sediments consist of mottled grey-chocolate brown clays, containing erratics and plates of vertically-oriented secondary gypsum crystals. A trench 3 m deep was dug into this clay horizon to obtain uncontaminated material for palaeontological and palynological work. However, no arenaceous foraminifera were found in five samples examined (Appendix 7). W.Harris (South Australian Department of Mines & Energy) analysed one sample (524-020) for pollen and spores, but results were negative, probably due to the oxidised nature of the material. Along the foreshore at Location J (Fig. 1) the Permian/Pliocene section is duplicated by slumping (Fig. 12).

MECHANISM FOR REPETITION OF PERMIAN/PLIOCENE

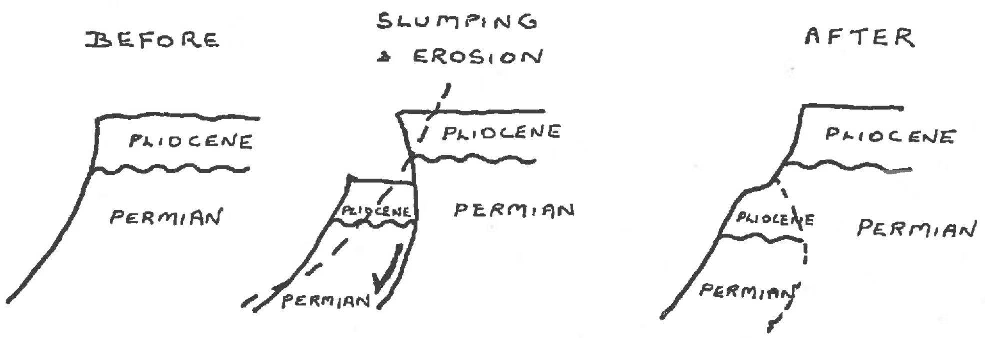


Fig 12.

Erratics

Large erratics occur in the Permian. Many have been reworked and litter the east coast beach (Plate 3). A quadrat 10 m x 3 m was measured for abundance and type (Table 4). Average erratic size was 40 cms x 20 cms. They include Encounter Bay Granites with characteristic blue quartz, abundant metasediments and other igneous rocks and gneisses, which indicate a southerly source for the Permian sediments.

Erratic type	Number
granite/granodiorite	33
Victor Harbour Granite suite	6
Wardang Island type volcanics	17
pegmatite	2
garnet-bearing schist	28
gneiss	6
quartzite	20
miscellaneous	122

TABLE 4.

Chemical analysis of the largest erratic (Plate 3) (Fig. 1, Location K) compares well with that given by Milne's (1973) Encounter Bay Granites at Cape Willoughby, Kangaroo Island (Table 5). The trace element chemistry of the Encounter Bay Granites varies considerably from one location to another, and thus allows elimination of all but the C. Willoughby location. Comparison with Milne's hand specimens (W1, W3, W32, W41) corroborated this source.

TABLE 5.

CHEMICAL ANALYSES OF GRANITE ERRATIC & C. WILLOUGHBY GRANITES

	WARDANG ISLAND	CAPE WILLOUGHBY		
	524-030	W1	W3	W32
SiO_2	71.98	72.8	72.6	73.8
Al_2O_3	12.61	13.1	12.9	13.1
Fe_2O_3	3.73	2.72	2.74	2.06
MnO	0.05	0.06	0.07	0.04
MgO	1.10	1.00	1.20	0.7
CaO	1.49	1.31	1.25	1.33
Na_2O	3.07	3.40	3.50	3.60
K_2O	4.51	4.48	4.63	4.65
TiO_2	0.56	0.41	0.47	0.35
P_2O_5	0.14	0.06	0.11	0.06
H_2O(loss)	0.72	0.53	0.57	0.62
Total	99.95	99.90	100.00	100.30
Rb	194	193	193	184
Sr	136	122	154	164
Y	45			
Ba	696			
Ce	123			
Nd	55			

PALAEOCURRENTS : Gastropod orientations

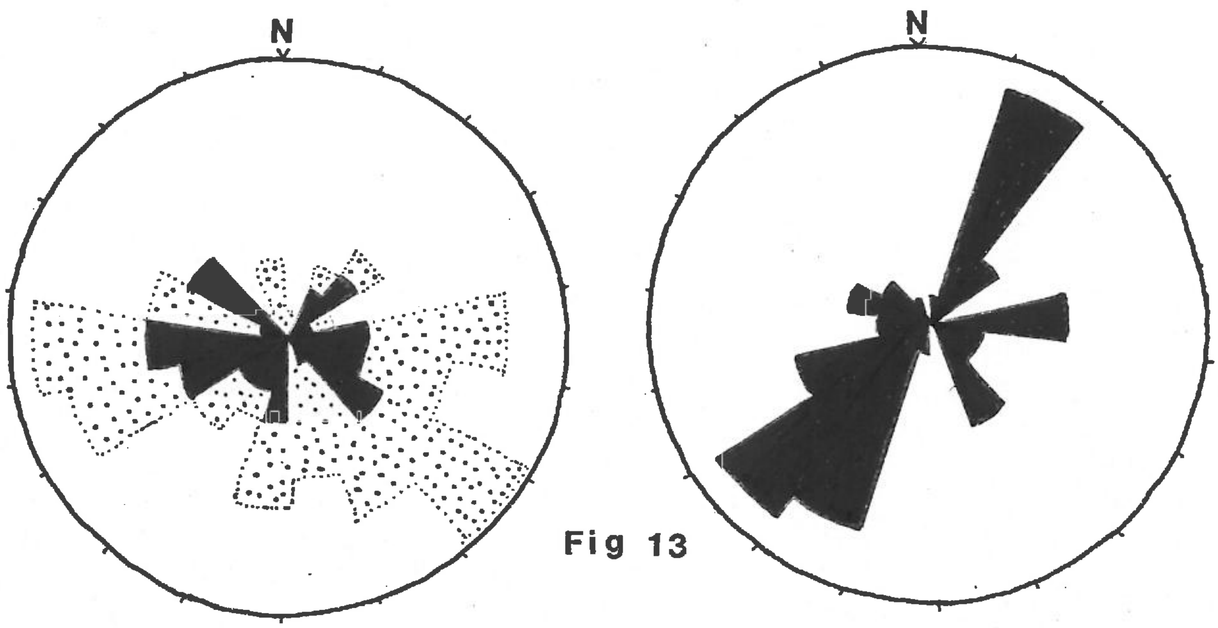


Fig 13

PLIOCENE

Cerithium potamides

No. of measurements = 37 (151 ⁙)

Circle radius = 10 measurement

⁙ not on same bedding plane

PRESENT

Phasianella australis

No. of measurements = 60

Circle radius = 10 measurements

This gives an ice movement direction of 340^{0}, which correlates with that given by the glacial grooves.

One erratic, 524-058, a metaquartzite, is striated and faceted (Plate 10), and will be housed in the Museum to be set up in the old schoolhouse on Wardang Island.

Chattermark Trails

Folk (1975) has suggested that trails of uniformly spaced crescentic marks occurring on the surface of mineral grains are pressure induced due to the grinding action of glacial ice and its load as it moves over bedrock surfaces. This is the same mechanism as that which produces chattermarks on polished pavements, except the chattermarks on the mineral grains are about four orders of magnitude smaller. Gravenor and Gostin (1979) have shown by petrographic analysis that about 50% of the garnets in the South Australian Permian retain delicate surface chattermark trails.

Therefore, to further authenticate the glacial origin of these sediments, samples were prepared (Appendix 8) and scanned. Both garnets and staurolites showed chattermark trails. Previous workers have published photomicrographs at x400 of these trails, and although they are incontrovertible the resolution is very poor (Plate 2). Therefore, the scanning electron microscope was used, revealing well-defined chattermark trails (Plate 2) and also grains that had been chemically etched by intra-stratal solution, subsequent to deposition (Plate 2).

The presence of chattermark trails on the surfaces of most of the garnet grains contained in heavy-mineral placer deposits now forming, indicates that these grains are derived from the Permian sediments rather than from grains released by weathering of the metasediment erratics (Fig. 1, Location L).

Hand specimen and thin section descriptions appear in Appendix 5.

PLATE 2

PERMIAN

1. Chattermark trail on garnet surface. S.E.M. photograph x 400.

2. Chattermark trail on garnet surface. S.E.M. photograph x 700.

3. Chattermark trail on staurolite surface. S.E.M. photograph x 700.

4. Chattermark trail on staurolite surface. S.E.M. photograph x 300

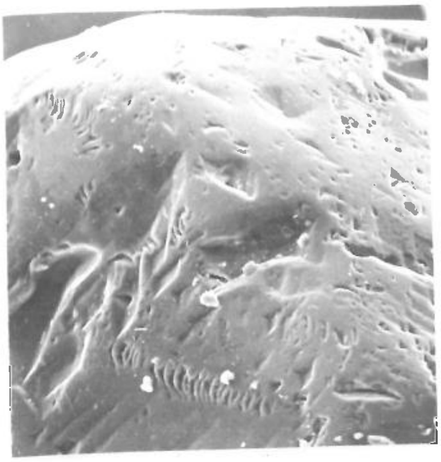
6\. Etch pits on garnet surface. S.E.M. photograph x 700.

5\. Chattermark trail on garnet surface. Photomicrograph x 450.

7. 524-051. Unsorted quartz arenite (tillite) with ferruginised matrix. Crossed polars. Location H (Fig. 1) x 30.

8. 524-001. Unsorted quartz arenite (tillite) with ferroan dolomite matrix. Crossed polars. Location H (Fig. 1) x 67.

PLATE 2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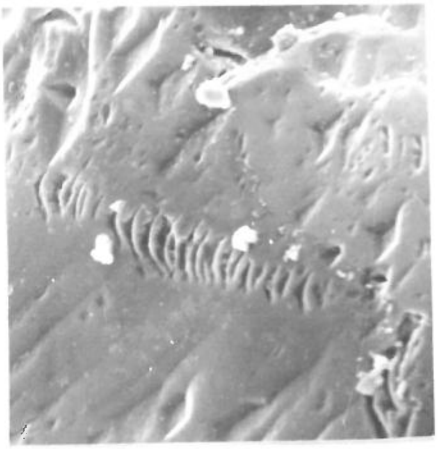
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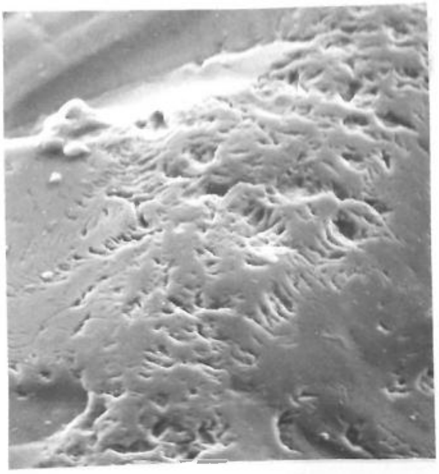
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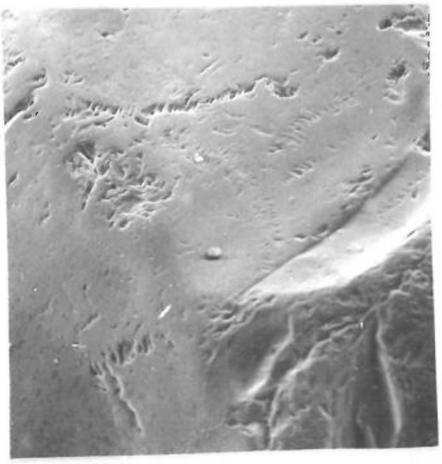
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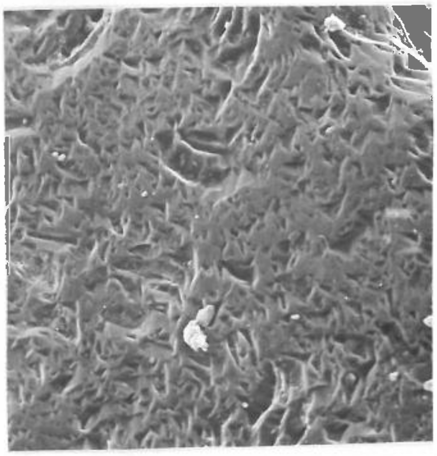
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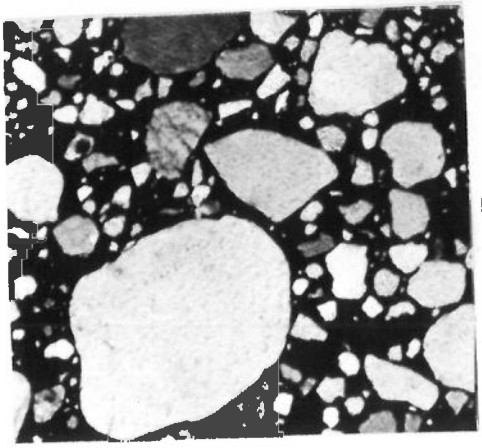
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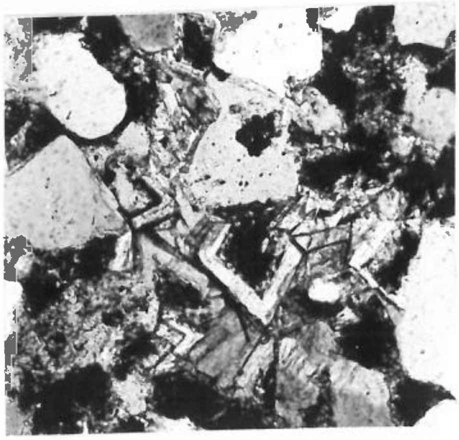
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PLATE 3

PERMIAN

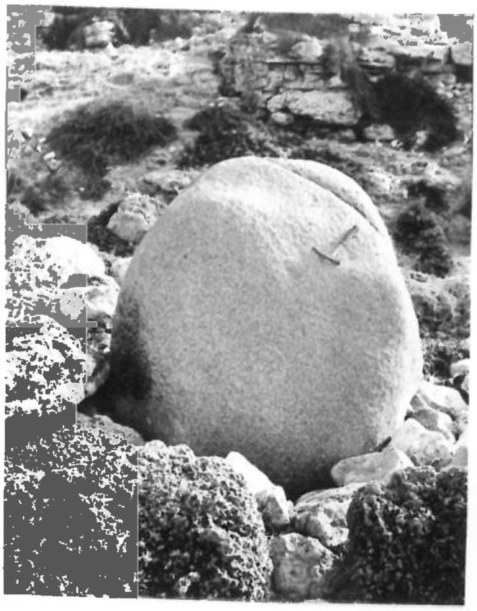
1. Unconformity between Permian and Pliocene, with granite erratic. Location I (Fig. 1).
2. Granite erratic derived from Cape Willoughby, Kangaroo Island. Location K (Fig. 1).
3. Reworked erratics on southern section of present day east coast beach.

PLIOCENE

4. Current oriented gastropod *Cerithium potamides* internal moulds. Location P (Fig. 1).
5. Basal conglomerate,with rounded, weathered clasts of porphyritic rhyo-dacite and amphibolite and *Anodontia sphericula* (articulated). Location O (Fig. 1).
6. Echinoid horizon - bioturbated. Location M (Fig. 1).
7. Pliocene Section. 'Cockle' horizon, 3 *A. sphericula* horizons, lagoonal-estuarine horizon, calcrete. Location M (Fig. 1).
8. Pliocene Section. Uppermost *A. sphericula* horizon overlain by laminar calcrete and cooler gastropod horizon - grading into calcrete. Location M (Fig. 1).

PLATE 3

1



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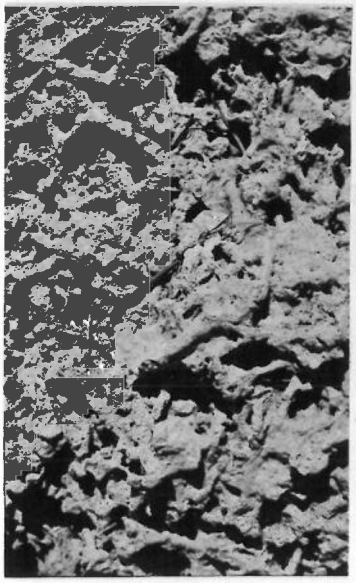

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PLIOCENE

The Pliocene sequence consists of fossiliferous sandy limestones (Plate 10) - the equivalent of the Hallett Cove Sandstone. It is more extensive (Fig. 1) than previously mapped.

Formation of Limestone

Chilingar et al. (1967) define limestone as "those rocks composed of more than 50% carbonate minerals, of which 50% or more consist of calcite and/or aragonite". The Wardang Island limestones have a high organic component. Commonly less than 5% of a local biota secretes hard parts of either aragonite, high-Mg or low-Mg calcite that survives in fossil form in the ultimate sediment (Bathurst, 1975).

These organisms probably use protein either as templates for heterogeneous nucleation of mineral carbonate or as a means of attracting the appropriate inorganic ions electrostatically. The problem of preventing the so-formed shell reacting chemically with the organism's enclosed body fluids is probably overcome by an organic film. This organic envelope is frequently preserved as a micritic rim (Plate 4).

The original unconsolidated sediments were dominated by two groups: (1) aragonitic molluscs and (2) high-Mg calcite foraminifera, coralline algae, bryozoa and echinoderms. Crickmay (1945) arranged organisms in an order of decreasing susceptibility to calcitization : corals > *Halimeda* > molluscs > pelagic foraminifera > beach foraminifera > larger foraminifera > echinoids > coralline algae. The Wardang Island Pliocene biota, though lacking corals, *Halimeda* and pelagic foraminifera, supports this order. The coralline algae have the highest $MgCO_3$ content and consequently should be the most susceptible to dissolution and yet they actually exhibit the least susceptibility. This may be due to "(1) wall structure; (2) organic conchiolin sheaths around crystals and (3) the small size of the ordered lattice domains in some of the apparently single crystals that look homogeneous but are really crystallographically heterogeneous" (Bathurst, 1975).

Banner and Wood's (1964) microfossil destruction work supports Crickmay's findings, except for placing the destruction of the coralline algae much earlier: chlorophyte algae, scleractinians > miliolids, peneroplids, alveolinids > planorbulinids, cycloclypeids, bryozoans, coralline algae > elphidiids, amphisteginids, echinoderms > textulariids, trochamminids. Nevertheless, absence may simply be because the organism did not occur in the area.

Diagenesis, although initiated in the marine environment, is comparitively rapid once the sediments are exposed to the atmosphere and wetting. The rapid formation of beach rock on Wardang Island (Plate 10) is shown by the inclusion of man-made artifacts such as bolts, rails etc. (between the two jetties). Within reach of sea water, the cement is high-Mg calcite, beyond it is low Mg-calcite. Within the subaerial environment cementation proceeds quite rapidly at surface temperature/pressure conditions.

Land (1966) proposed a 5-stage limestone fabric evolution:-

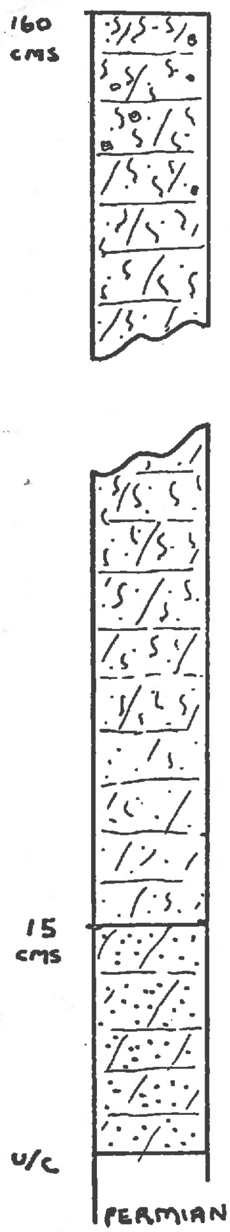
1. <u>unconsolidated mineral assemblage</u> - bioclasts;
2. <u>first cement</u> - low-Mg calcite on surfaces of grains near points of contact - or uniformly distributed fringe of aragonite. A meniscus between the cement and pore implies precipitation in the vadose zone from water localised around the points of grain contact;
3. <u>loss of Mg^{++}</u> - the only minerals now present are aragonite and low-Mg calcite, although there are no visible signs of dissolution;
4. <u>dissolution-precipitation</u> - aragonite dissolves but the porosity remains relatively constant, as the development of secondary porosity is countered by the deposition of calcite cement. The cement is autochthonous (Plate 4);
5. <u>culmination in low-Mg calcite</u> - porosity is approximately 20%. Any further cement would probably need to be allochthonous (Plate 4).

During these processes the pH of the groundwater can become sufficiently high (>9) to cause the dissolution and consequent embayment of enclosed quartz grains (Plate 4).

The type of cement varies depending on stage, location, composition, supply etc. In the early stage of diagenesis, microcrystalline calcite (micrite) infills voids, both inter- and intra-particle. Thus geopetal features can be formed (Plate 4). Micrite also replaces the organic rim around many organisms (Plate 4). Secondary calcite, in the form of bladed spar, may then grow outwards from this rim into voids (Plate 4). Later, neomorphic spar (Folk, 1965) is formed by older crystals, e.g. micrite being 'consumed' and their place being simultaneously occupied by new crystals of the same mineral or a polymorph (Plate 4). This material is sometimes termed sparry calcite, but sparry calcite may also result from the secondary infilling of voids (Plate 4), which can give pseudo-geopetal structures (Plate 4). Bathurst (1975) feels that on the regional scale neomorphic spar reflects a pattern related to time - "but in detail the pattern is untidy, reflecting local variations in movement and composition of ground-water and the inevitable slowness and inefficiency of diagenetic processes".

Looking specifically at the Wardang Island Pliocene sequence, the fossil fauna is dominated by Mollusca and benthonic foraminifera, but with marked variation in the vertical section, reflecting differing environmental conditions. The diverse assemblage is akin to the tropical genera inhabiting warm and shallow waters of the Indo-Pacific region to-day (Ludbrook, 1954). Data from D.S.D.P. site 284 and from N.Z. indicate that relatively stable conditions pertained during the early Pliocene, with cooling in the late Pliocene (Savin, 1977). Shackleton & Kennett (1975b) have suggested that the late Pliocene cooling corresponds to the initiation of glaciation in the Northern Hemisphere. Cooper (1977) notes that population explosions appear to be triggered by the increased trophic resources accompanying marine transgressions of inter-glacial periods. The species, once established, do not always become extinct during the ensuing regressions, but rarely dominate the later faunas to the same extent. This is supported by marked decreasing diversity and density towards the top of the sequence. Difficulty is encountered in determining the actual Pliocene-Pleistocene boundary. Twidale et al. (1976) "Believe the Hallett Cove Sandstone should be re-defined to exclude the upper bed of Pleistocene (?) marine limestone of lagoonal to estuarine environment". As the Wardang Island section measures 4.2 m (Fig. 1, Location M) in comparison to the 5 feet or less thickness of most South Australian Pliocene outcrops (Ludbrook, 1959) and shows ten distinct horizons, it is suggested that this section is worthy of further work.

Pliocene Section



sharp boundary — Plate 3

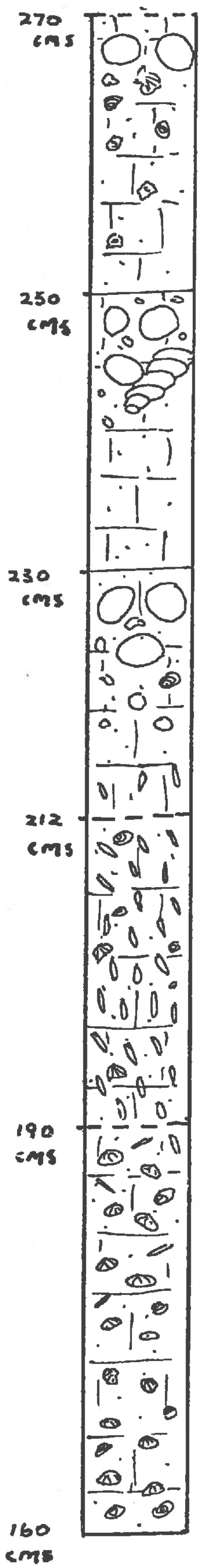
A foraminiferal-rich fossiliferous sandy limestone without bedding. Staining shows calcite cement (Appendix 6). The horizon grades upwards into highly bioturbated material (Plate 3) containing many small ($\leq$ 2 cms) infaunal echinoids and large ($\leq$ 3 cms) specimens of the soritid foraminifera *Marginopora vertebralis*. The distributional pattern of *M. vertebralis* indicates that it thrives and proliferates in somewhat sheltered waters of algal pools on the reef flats and the back-reef regions and attains the highest growth rates at depths of 8-10 m (Buchardt, 1977). Its distribution throughout the section is probably related to post-mortem current activity. Thin section examination shows a *Peneroplis* sp. and many miliolids, indicative of the inner shelf zone (Plate 4).

524-211 524-222 524-223 524-207

Permian U/C Basal Pliocene — sharp boundary — Plate 3

A poorly fossiliferous sandy limestone showing bedding ($0^{o}/7^{o}$W), revealing ferroan dolomite cement upon staining (Appendix 6). Detrital garnets and poorly sorted rounded and angular quartz grains were derived from the Permian. Nevertheless, the benthonic foraminifera (*Discorbis* sp.) and coralline algae present (Plate 4) indicate a Tertiary age and marine origin. No diagnostic Miocene foraminifera were found, so a Pliocene age is assumed. No phosphate was found directly above the unconformity surface (Appendix 10).

524-210 524-213 (ferroan dolomite) 524-220 524-221



transitional boundary

These 3 horizons contain prolific, large globular clasts of the thick shelled bi-valve *Anodontia sphericula*. This "cockle" has been known as *Dosinia greyi* and *Meretrix sphericula*, but "the adductor impressions and the pallial lines are those of the Lucinidae" (Ludbrook, 1959). Frequently associated with *A. sphericula* is the large gastropod *Cerithium potamides* (Plate 3), usually showing the effect of the boring sponge *Clione* sp. Each horizon fines upwards, with the next boundary being sharp. A scouring and slumping effect is seen in some areas.

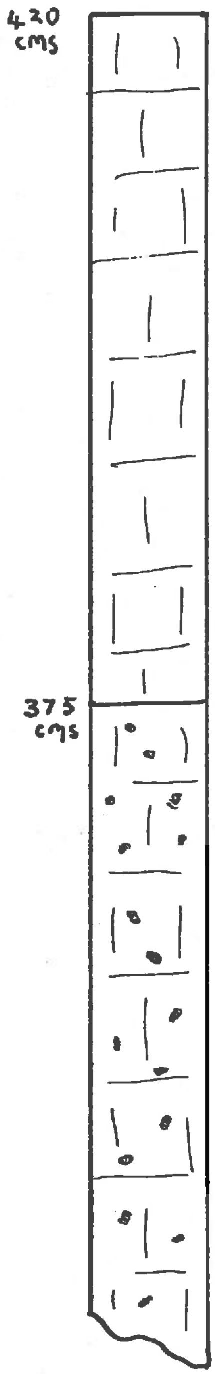
transitional boundary

This horizon contains abundant internal moulds of articulated shells of the mussel *Brachyodontes* sp. with minor *Ostrea* sp. and large *M. vertebralis* indicating a low energy regime and a sandy bottom.

transitional boundary

A richly fossiliferous horizon with abundant bivalvia moulds (Plate 6), unsuitable for identification purposes. Most of the bivalvia are disarticulated, indicating that this may have been a strand line of the shallow Pliocene sea or the result of post-mortem current activity. This horizon is the richest source of large *M. vertebralis*.

524 - 224



transition boundary Plate 3

The uppermost part of the section consists of calcretized fossiliferous limestone. Three distinct types of carbonate can be seen in thin section:

(a) micrite supporting lithoskels, mainly broken fragments of molluscs, indicating that this may have been an old shell-hash bed. There are also ubiquitous miliolids.

(b) laminar calcrete, with many quartz clasts and showing iron staining, and

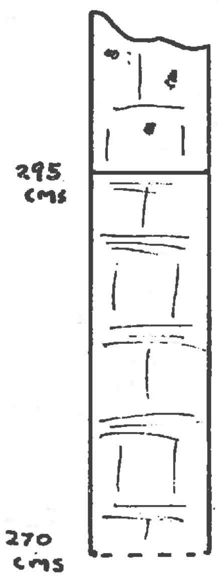
(c) equant spar veins (Plate 4). Calcretization is discussed in more detail in the calcrete section.

524-215 524-329

sharp boundary Plate 3

This horizon contains fewer macro-fossils. These are mainly small gastropods and some algae (Plate 4). Thin sections reveal a predominantly *Triloculina-Quinqueloculina* foraminifera population (Plate 4). This would appear to be the lagoonal estuarine facies that Twidale et al. (1967) suggest should be assigned to the Pleistocene. If not, then it certainly represents a cooler stage of the Upper Pliocene.

524-204 524-214 524-328 524-330



sharp boundary Plate 3

This horizon has undergone calcretization in part, exhibiting a laminar habit. Thin section examination shows that the laminae consist of micrite, with minor spar veinlets. There are minor lithoskels with indistinct boundaries.

524-337

PLATE 4

PLIOCENE

Photomicrographs

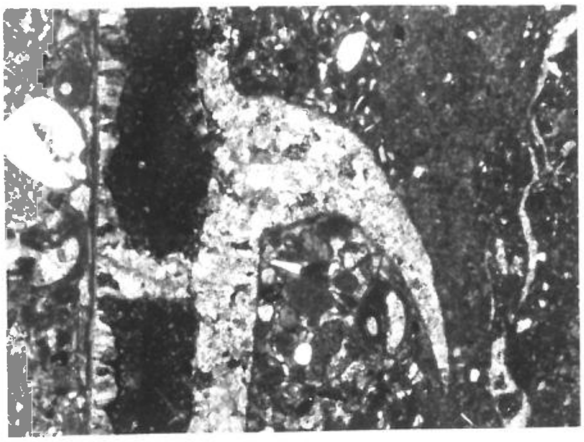
1. 524-213. Calcrete-Pliocene horizon. Aragonite of bivalve has dissolved and void is being infilled with spar. Micrite rims preserved on bivalve. Calcretization advancing upon spine. Micritic calcrete boundary indistinct. Location M (Fig. 1) Plane light x 17.
2. 524-210. Basal Pliocene. Poorly sorted and poorly rounded quartz grains supported by ferroan dolomite matrix. *Discorbis* sp. foraminifera indicates marine Tertiary sediment. Location I (Fig. 1). Crossed polars. x 30.
3. 524-214. Lagoonal-estuarine horizon. Gastropod has micritic rims preserved, aragonite shell dissolved and replaced by spar. Miliolids abundant. Location M (Fig. 1). Plane light x 30.
4. 524-205. Lowermost *Anodontia* horizon. Shows embayed quartz grain, echinoid fragment and coralline algae. Location M (Fig. 1). Crossed plars. x 30.
7. 524-211. Echinoid horizon, showing *M. vertebralis, Peneroplis* sp. and many Miliolids. Location M (Fig. 1). Crossed polars. x 17.
8. 524-203. Transitional with calcrete. *Discorbis* sp. shows pseudo-geopetal features due to neomorphic spar development. No calcretization apparent. Location M, (Fig. 1). Plane light. x 30.

QUATERNARY

Photomicrographs

5. 524-300. Bryozoal limestone from Saltmarsh beach. Bryozoal and echinoid fragments are infilled with micrite, which shows neomorphic spar development. Micrite rims of bioclasts. Bladed spar growth from rims, micrite rim on bladed spar and secondary infilling of voids with equant spar. Plane light. x 30.
6. 524-300. Geopetal structure.

PLATE 4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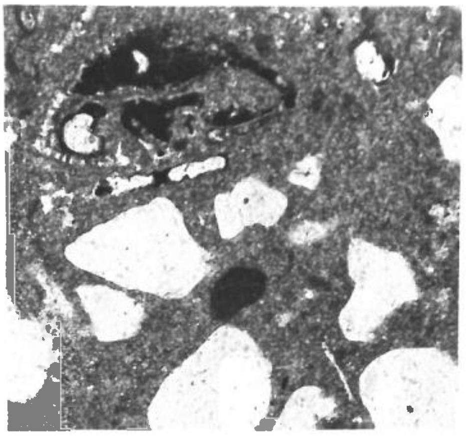
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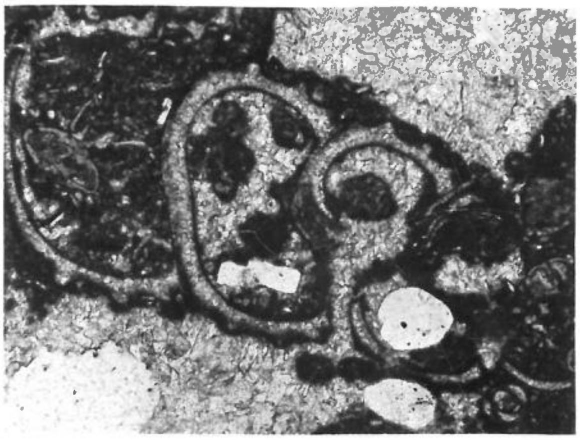
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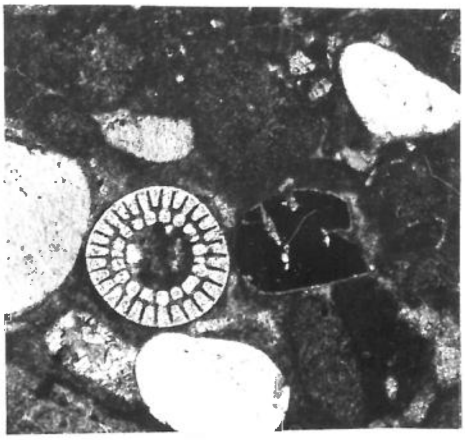
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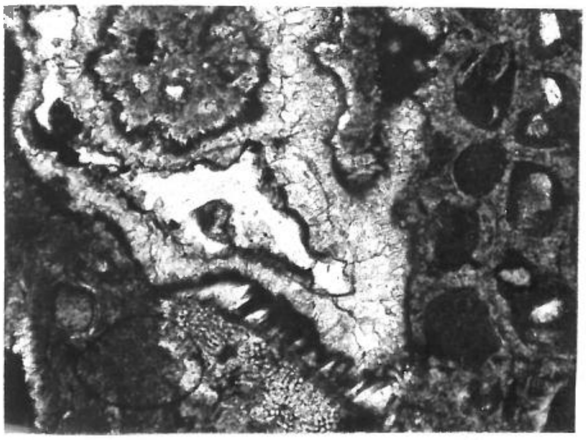
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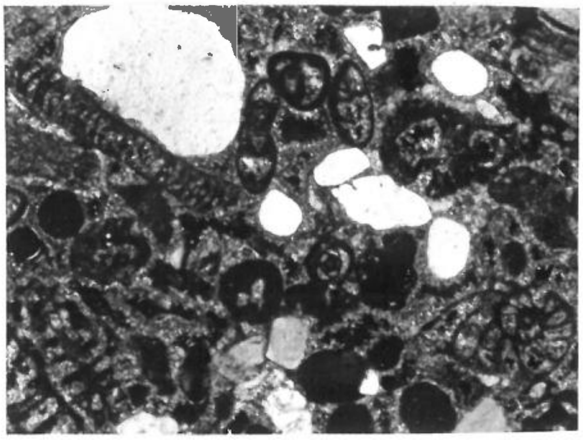
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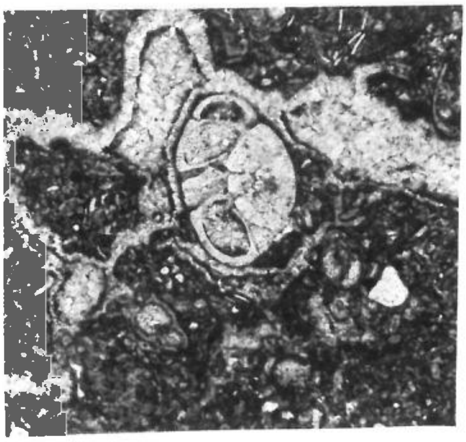
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Traversing westwards, the *Anodontia* horizon becomes lower in the section and finally rests unconformably upon the Basement. At Locations N and O (Fig. 1) the basal Pliocene is conglomeratic, containing quite large Basement clasts, representing a high energy regime or alternatively a re-worked regolith, yet the *Anodontia* were fossilized in an articulated condition (Plate 3).

At Location O (Fig. 1) there is evidence of the "ferruginisation that occurred on Yorke Peninsula and Eyre Peninsula during the late Pliocene and early Pleistocene (Twidale 1976). On Wardang Island the ferruginisation is a Pliocene event, as the ferruginised horizon is both underlain and overlain by *Anodontia* containing limestone. There is also evidence of a pre-Pliocene tectonic event, which caused brecciation of the Basement and the intrusion of quartz veins. These appear to cut the Pliocene (Plate 10) but this may be fortuitous. The Pliocene has probably been deposited around the protruding veins.

On the eastern coast, an attempt was made to re-construct palaeo-currents by measuring the orientation of *C. potamides* on a bedding plane on a 10 m x 2 m quadrat (Location P, Fig. 1) (Plate 3) and comparing the results with those obtained similarly of present day *Phasianella australis* on the present day beach. The results (Fig. 13), although not conclusive, do suggest that the Pliocene currents operated from a similar direction to those now pertaining.

A count of articulated *Anodontia* specimens on the same quadrat gave abundances of up to $52/m^2$. Habitat requirements and trophic resources must have been at optimum levels for this organism during the Pliocene to give counts of this magnitude!

Hand specimen and thin section descriptions appear in Appendix 9.

QUATERNARY

The Pleistocene boundary outside the stratotype region is in dispute. The Pleistocene was a time of world-wide eustatic sea-level changes related to the waxing and waning of ice-caps. During the Pleistocene extensive accumulations of aeolianite and a number of calcrete horizons were formed on Wardang Island.

Sea-Level Changes

Evidence for high sea-levels in the form of raised beaches is seen on the west, east and north coasts, with the most extensive on the east. Here there is a series of N-S trending ridges (Fig. 1) littered with discoidal, moderately-sorted cobbles of Basement, reworked Permian erratics, Pliocene and beach rock material (Plate 5). The most pronounced ridge, approximately 2-3 m above present mean sea level, probably represents the 125,000 year B.P. transgression (Riss-Würm interglacial - Fairbridge (1961)). Small specimens (<1 cm) of *M. vertebralis* occur in post Pliocene fossiliferous cobbles on this stranded beach, but no other diagnostic Glanville Formation fauna are present, e.g. *Anadara trapezia*. The ridges are analogous to the stranded ridges of Hails and Gostin (1978) on the east coast of Eyre Peninsula, north of Backy Point.

A stranded cliff of karst-weathered calcrete extends for approximately 0.5 km from the small jetty southwards (Fig. 1), some 300 m from present high-tide mark. It is underlain by a stranded-ridge composed of fossiliferous limestone.

A later high sea-level can be inferred from the shell-hash beds which are prolific throughout the eastern half of the present salt marsh (Plate 5). These beds are unconsolidated and have not been subjected to carbonate cementation. Little to no dissolution of the aragonitic molluscs has occurred, suggesting that they have not been subjected to prolonged wetting within the fresh water phreatic zone. They stand at a maximum of 1 m above present sea level. A thorough search failed to reveal any *M. vertebralis*, suggesting that these beds should be assigned to the St. Kilda Formation. The

PLATE 5

QUATERNARY

1. Aeolianite wave-cut platform. Platform indicates previous sea level high; aeolianite indicates previous sea level low. West Side.
2. N-S trending stranded shingle beach ridge. Southern section of Saltmarsh.
3. Shell hash beds. Northern section of Saltmarsh.
4. Cross-bedded aeolianite - indicating a dominant S-W wind direction. Beach south of Quarry.
5. 524-314. Aeolianite from Airstrip Well. Dominant bioclast is coralline algae, plus Rotaliid foraminifera. Matrix is fine calcite. Plane light x 30.
6. Aeolianite-calcrete-fossiliferous limestone section, Location R (Fig. 1), indicating palaeoclimatic and sea-level changes.
7. Recent mobile dune, south of Lighthouse. This dune has formed within the last 15 years.
8. Aeolianite cliffs showing prominent continuous calcrete capping. In the foreground the porphyritic rhyo-dacite is cut by an amphibolite dyke. Opposite Pigeon Island.

PLATE 5


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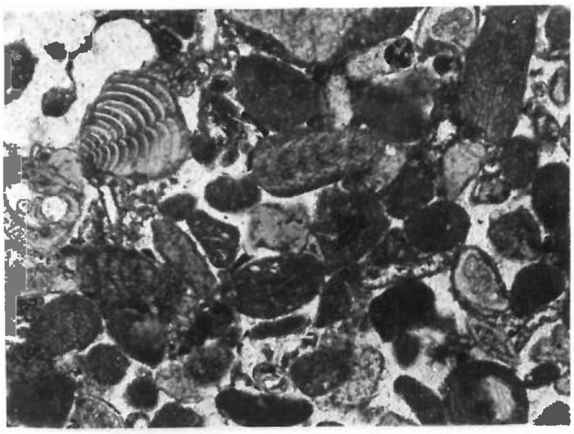
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calcrete horizon underlying them and overlying the possible Glanville Formation stranded ridges probably belongs to the Bakara horizon of Firman (1969).

Regressions can be inferred by the existence of features which formed subaerially, but now extend below sea level. Such features are the extensive aeolianite wave-cut platforms on the west coast (Plate 5) and the calcretized reef which extends from the north coast to Goose Island.

When assessing sea-level changes, local tectonic effects must be considered. The postulated E-W faults (Fig. 1) appear to have off-set the aeolianite sequence, but not the main calcrete horizon.

Aeolianite

It is impossible to pinpoint the time of accumulation of South Australian aeolianites (von der Borch, pers. comm.). Nevertheless, Firman (1969) assigns them to the Bridgewater Formation. They accumulated during stand stills and contain cross-bedding indicating a southern wind-direction and source.

The bright orange coloured aeolianite deposits on Wardang Island differ from other off-shore island deposits, inasmuch as the southern end of the island is devoid of dunes, whereas they occur extensively on the northern and western sides. This may well have been partly controlled by the E-W faults which were then active, having their downthrown block to the south (Fig. 1).

Cross beds with a dip of 10-20^{o}N in the aeolianite adjacent to the jetty indicate a southern source, whilst on the west coast, the "swiss cheese" cliffs indicate a wind direction dominantly from the S-W (Plate 5).

The few terrestrial gastropod fossils are of no real age value. Thin sections reveal that the majority of the clasts are coralline algae, probably *Corallina cuvieri* var. *crisparta* (Prof. H.B. Womersley, pers. comm.), with approximately 5% each of foraminifera, echinoid fragments and quartz grains (Plate 5). This contrasts with other locations, e.g. Pt. Elliott and Kangaroo Island have approximately 50% quartz grains as do those of the

South East (Schwebel, pers. comm.). The lithoskels are weakly cemented by micrite, easily crumbling between the fingers.

Evidence of cessation of deposition and more humid conditions can be seen in many places where fossil soils and calcrete horizons occur within the aeolianite section (Fig. 1, Location Q). The fossil soils, calcretes and

CALCRETE - FOSSIL SOILS - WASHAWAY LOCATION

SCALE 1 cm : 1 m

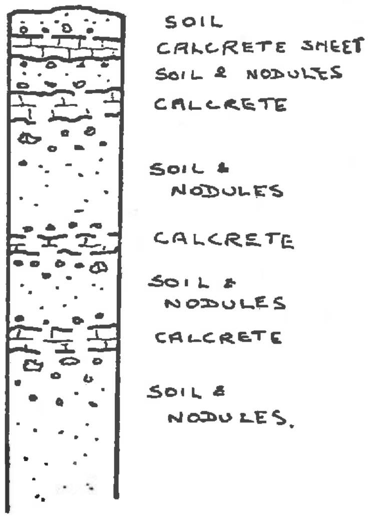

Fig 14

root horizons mark periods of "local still-stand" (Playford & Leach, 1977) in dune development i.e. hiatuses between successive aeolianite accumulations.

An interesting sequence on the Northern coast (Fig. 1, Location R) shows alternating calcrete and truncated aeolianite horizons overlain by fossiliferous limestone (Plate 5). The latter is approximately 2 m. above high tide mark and correlates with the raised beach at 2 m above sea level seen on the East and West coasts. Dating of this material would place constraints on the upper boundary of the time of deposition of the aeolianite.

Gill (1978) discusses the importance of aeolianite studies in sea level changes. Whereas quartz sand dunes become rapidly deflated or eroded when stranded, the depositional and erosional features of calcareous dunes are preserved due to the secondary deposition of carbonate.

Sand Dunes

In the early part of the century the calcareous aeolianite was mined by Broken Hill Associated Smelters and shipped to Pt. Pirie as a flux.

Later, it was found that the carbonate content of the recent mobile dunes was even higher than that of the fossil dunes. Thereupon, the mobile dunes were steadily bull-dozed until by the early 1960's they had vanished, with only fixed dunes remaining. Now, some 15 years later, longitudinal mobile dunes are once again forming (Plate 5). The prevailing wind is from the S-W, with gale force 'northerlies' common during the equinoxes, accounting for the 50^{o} trend shown.

Stratigraphically the dunes can be assigned to the Semaphore Sand (Firman, 1969). The composition is similar to the material of the dunes fixed by vegetation, which can also by erosion contribute to the mobile dunes although their major source is undoubtedly from the intertidal zone. A variety of foraminifera (Plates 7 & 8) are the dominant clasts, although important bioclasts are calcareous algae, mollusc larvae, sponge spicules, ostracods and bryozoa.

Several classical examples of blow-outs (Fig. 1, Location S) occur on the S-W facing fore-dune areas.

Calcrete

Attempts have been made to use calcretes as regional stratigraphic time markers (Firman, 1969), but on the whole the ubiquitous cross-cutting and anastomosing calcrete horizons on Wardang Island do not support this hypothesis. Rather, they support the hypothesis that calcrete formation is a local event, tied predominantly to the local climate and topography and to a lesser extent to a supply of calcium carbonate. Nevertheless, there is one prominent continuous calcrete capping that can be traced for some kilometres overlying the aeolianite. (Plate 5).

The only sequence not overlain directly by calcrete is the Permian. Contacts are shown from transitional over the Pliocene (Plate 3) to cross-cutting in the aeolianite (Plate 6) to sharp over the Basement.

The calcretization process is similar to the calcitization process discussed earlier. However, the cement is allochthonous and there is frequently a decrease in grain-size and consequent reduction in porosity. The

$CaCO_3$ for the cement can be made available by various processes:-

(1) progressive dissolution of overlying material by percolating rainwater;

(2) upward movement by capillarity due to evaporation being greater than infiltration. If this were so, then one would expect to see geochemical differences in the calcretes formed, reflecting the underlying bedrock. Table 6 shows that on Wardang Island this is so, with respect to the trace element geochemistry, so this process undoubtedly plays a major part in their formation;

(3) influx of sea water - would expect high Sr and Mg counts for this process. Unfortunately no suitable calcretes were analysed to test this hypothesis, but geochemical variation does not support the hypothesis. Sea water spray is undoubtedly a source in coastal areas, however.

(4) pressure solution. Where grain boundaries are still preserved, little evidence can be seen of pressure solution at contact points. Therefore this process is not considered to have been of major importance;

(5) rainwater. Schwebel (pers. comm.) calculated that calcium carbonate in the sequences in the Robe area could have been totally supplied by rainwater, using present day content and estimating an average of 10,000 years for the formation of each sequence. Nevertheless, this process would not explain the geochemical variations.

Therefore, it seems feasible that processes (1) and (2) are responsible for the Wardang Island calcretes. With process (1), nucleation and deposition of micrite around detrital grains occurs. Nodule growth increases until eventual coalition of nodules forms a massive sheet of blocky calcrete. As the process continues, auto-brecciation may occur, with self-healing by the deposition of spar (Plate 6). Small anticlinal structures can be formed as a consequence of the auto-brecciation (Blank & Tynes, 1965) (Fig. 1, Location T). Simultaneously, due to the impermeable nature of the sheet, a film of super-saturated water (P_{co_2}) in soil can be ten times greater than in the underlying carbonates,(particularly if vegetation is involved) forms on the upper surface, depositing a thin lamina of calcrete. Repetition of this process occurs, as does nodule formation in the overlying soil profile. The consecutive layers tend to be different colours, ranging from pale buff to dark red-brown-black. Geochemistry did not reveal an inorganic cause (Table 6). It has been suggested that the cause may be due to variable organic contents of groundwater, but the laminae on the undersurface of the massive sheet show the same effect. If process (2) is occurring contemporaneously, then an inversion of process (1) occurs and the variable geochemistry is explained. Thus, processes (1) and (2) combined satisfactorily explain the formation of laminar calcrete both on top and below the massive calcrete seen at various localities.

Where the material being calcretized is already a lithified carbonate (e.g. the Pliocene) then different processes can be invoked. Here an in situ grain by grain 'engulfment' by smaller grained micrite occurs (Plate 4). The same order of further destruction of fossils occurs, with the loss of foraminifera families following Banner & Wood's (1964) order (Plate 4). It is often difficult in the field to decide whether the outcrop has been partly calcretized, as this process does not give a sharp contact. Many apparent calcrete boulders above the Pliocene sequence reveal 'normal' fossiliferous cores when broken, suggesting that the calcretization initiates along joints and works inwards.

Rhizocretions of various types occur. In the Pliocene they form an integral part of the sequence, probably where roots have penetrated joints (Plate 6). In the aeolianite they are the well-known 'pipe' type. In the vicinity of the Lighthouse they occur as small relict vertical pillars projecting from the underlying soil after wind removal of the surrounding soil/aeolianite.

An analysis of the loose, crumbly 'clay' infilling joints in the calcrete at Location U (Fig. 1) (Plate 6) was made, to see whether the clays sepiolite and palygorskite commonly associated with mainlaind calcretes (Callen, 1977) were also present in the Wardang Island calcretes. X.R.D. analysis (Appendix 12) revealed no sepiolite or palygorskite, the common

CHEMICAL ANALYSIS OF WARDANG ISLAND CALCRETES

	Calcreted Pliocene - Well S.End 524-219	Calcreted Pliocene S. End 524-299	Well Calcrete 524-301	Calcrete over Aeolianite 524-321	Calcrete over Dyke 524-322	Calcrete Quarry 524-324	Calcrete Pliocene 524-327	Calcrete Black Rocks 524-340 (over Porphyry)
SiO_2	6.81	3.70	9.20	1.04	17.34	8.16	0.74	11.90
Al_2O_3	1.99	1.01	3.11	0.17	1.44	2.00	0.25	3.00
Fe_2O_3	1.12	0.47	1.69	0.30	0.48	0.82	0.14	1.22
MnO	0.02	0.02	0.03	0.00	0.01	0.05	0.01	0.02
MgO	0.88	1.44	1.12	3.62	2.04	1.98	0.98	1.93
CaO	48.66	51.35	45.53	50.98	41.68	46.71	53.26	43.94
Na_2O	0.28	0.32	0.33	0.17	0.25	0.36	0.02	0.34
K_2O	0.20	0.05	0.24	0.01	0.09	0.22	0.02	0.24
TiO_2	0.10	0.04	0.16	0.01	0.07	0.11	0.01	0.17
P_2O_5	0.07	0.07	0.08	0.06	0.13	0.07	0.07	0.09
Loss	(40.18)	(47.12)	(38.63)	(44.12)	(36.40)	(39.71)	(43.86)	(37.41)
Total	100.31	100.59	100.12	100.48	99.93	100.19	99.36	100.26
Zr	38	12	45	1	30	42	6	56
Nb	8	0	5	5	5	7	3	10
Rb	14	3	16	0	6	7	0	12
Sr	388	582	357	594	1011	1097	562	697
Y	7	7	29	6	6	4	0	8
Ba	161	322	111	6	58	92	254	87
Ti	783	297	1199	36	453	638	64	254
Ce	75	75	105	78	67	72	65	70
Nd	29	25	64	20	14	27	20	22

TABLE 6

PLATE 6

QUATERNARY

1. Calcrete rhizocretions in 'cockle' horizon of Pliocene. Adjacent to Location K(Fig. 1).
2. Calcrete horizons and fossil soils exposed in Washaway, West side.
3. 524-324. Calcretized aeolianite from the Quarry, West side. In situ dissolution of the aeolianite is seen on the right, laminar calcrete in the centre and massive calcrete on the left, with minor spar veinlet. Plane light. x 17.
4. 'Clay' infilling joints in calcreted Pliocene. Location U (Fig. 1).
5. Prograding barrier beach, south of Bird Point. Young *Arthrocnemum arbuscula* in the foreground, with *Salicornia quinqueflora* mounds being inundated by incoming tide.
6. Major tidal inlet flanked with *A. arbuscula*, Saltmarsh area. *Posidonia australis* leaves with adhering calcareous biota are stranded on vegetation.
7. Crinkled mats & dessication flakes of blue-green algae. Bird Pt.

PLATE 6


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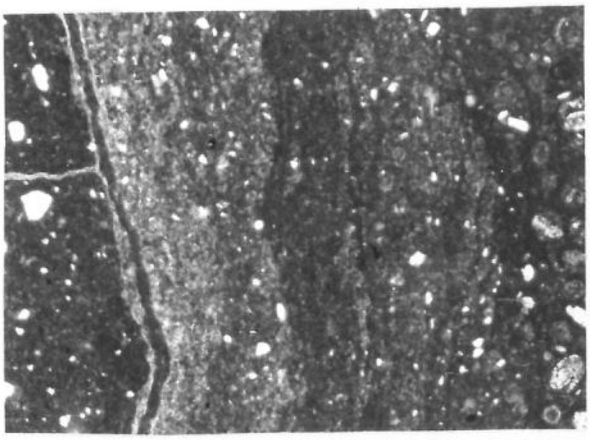
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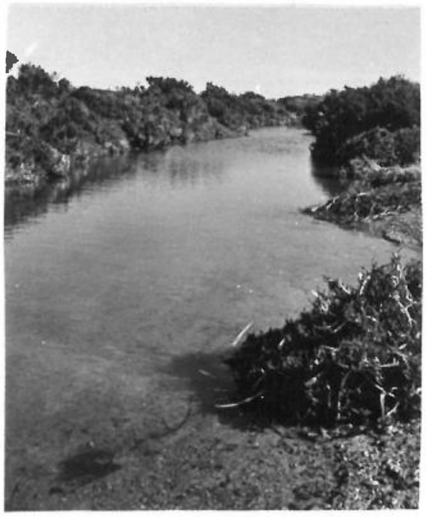
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minerals being quartz, feldspars, chlorite, alunite, sericite and illite.

Quaternary - Saltmarsh

The Wardang Island saltmarsh represents a classic example of a prograding barrier beach. Comparison of Lands' Department aerial photos taken in 1950 and 1972 emphasise that progradation is a remarkably active process, occurring at measurable rates over short time spans (0.25 m/10 years).

The western margins of the salt-marsh, beyond the reach of all but the highest storm spring-tides, contain small salt flats (sabkhas). Halite and gypsum are the only evaporitic minerals currently being precipitated. Small-scale tepee structures form in autumn and late-summer, due to upward heaving of the surface due to underlying growth of halite and gypsum.

The salt-marsh is covered by low shrubby halophytic Chenopodiacae - predominantly *Salicornia quinqueflora, Suaeda australis* and *Arthrocnemum halocnemoides*, all of which can tolerate salinities of 0.3-1.0% (Specht, 1972). This area is not subject to diurnal flooding, but is threaded by a net-work of anastomosing tidal inlets, which become inactive as easterly progradation progresses.

The stranded ridges that traverse the salt-marsh have been colonized by the xerophytic *Atriplex paludosa - Olearia* sp. associes. The 'soils' of these ridges have a high porosity and minimal organic and clay content.

There are no mangroves on Wardang Island. Rather, this habitat has been colonised with equal success by *Arthrocnemum arbuscula*, which can tolerate 16-17% total soluble salts (Specht, 1972). It forms a low woodland fringing the shore and tidal inlets as far as the limit of regular tidal flooding (Plate 6).

On the sea-ward margin *S. quinqueflora* is actively colonising the tidal flats as sediments accumulate (Plate 6). This is somewhat cyclic, as the vegetation enhances the trapping and deposition of detritus - both organic and inorganic. The sediments are coarse to fine grained, with a high carbonate component (approx. 85%) and in all but localised areas where sea-grass debris has accumulated, lack a reducing zone to a depth of at least 0.5 m. This contrasts with analogous areas, e.g. Pt. Gawler, where a reducing zone is encountered at shallow depths, often within the top centimetre. However, the Wardang Island saltmarsh area is not receiving any terrigenous clay fraction and so a porous, friable texture is maintained, enabling aeration of the sediments to considerable depth.

In the shallow water to the east, marine angiosperms have become established, with a marked zonation controlled by depth. The seagrass *Zostera muelleri* occurs in the shallower waters (<2 m) and on flats exposed at low tide, whilst *Posidonia australis* forms a dense sward from approximately 1 m to deeper waters. These two are the dominant sea-grasses, but others and algae occur, all providing suitable ecological niches for the variety of fauna, both micro- and macroscopic that inhabit the area and, upon death, become such an important component of the sediments (Plate 11).

Throughout this entire environment, the fixation of deposited sediment is enhanced by surficial mats of blue-green algae which colonise the top few millimetres. Particles adhere to the mucilaginous-like sheath surrounding the algal filaments, which with continuing growth allow further trapping of the sediment. Where the mats are aerially exposed for some time, desiccation occurs to the stage where the mats are fragmented, the flakes (Plate 6) contributing to intraformational conglomeratic limestones. The algae play a major role in the progradational process, by preventing tidal re-cycling of the newly deposited material.

Foraminifera

Foraminifera are small protozoans (usually < 0.5 mm) that either secrete calcareous tests or agglutinate foreign material to form a test. Benthonic forms are prolific on Wardang Island. Their tests, either upon death or vacation, become the dominant component of the sands. Much work has been done on foraminiferal habitats (e.g. Murray, 1973), so that useful extrapolations regarding palaeoenvironments and palaeoclimates can be made from analyses of living assemblages. Each type of bottom produces a distinct population of foraminifera, so that large species often with much thickened central area, are found on sandy mud bottoms, e.g. *Peneroplis* sp. between Goose Island and Wardang Island. In the prograding beach area heavy muds have even larger species with more flattened tests, e.g. *Elphidium* sp., whilst the smallest species, e.g. *Fissurina*-Miliolid sp. occur in fine muds which are almost a suspension as heavier species would sink into the mud. Species that move about over a firm muddy bottom, e.g. *Elphidium* sp. commonly are discoidal or much flattened trochospiral. Thin discoidal tests and attached forms may be found on seaweeds, e.g. *Nubecularia* sp. and *Annulopatellina* sp. Lenticular forms occur on algal fronds and on heavy mud bottoms, e.g. *Polymorphinid* sp. Equally important are water depth and turbidity. In shallow water of algal facies, Discorbidae and Textulariidae are abundant whereas with increased depth where algae are less abundant the Buliminidae appear. Hence, the abundance of species of *Triloculina* and *Quinqueloculina* (Plate 4) in the Upper Pliocene (?Pleistocene) suggests a lagoonal-estuarine environment. Today, these same forms dominate the east coast Wardang Island saltmarsh prograding beach assemblage.

The reef environment between Goose Island and Wardang Island has an assemblage dominated by *Peneroplis-Spiroloculina-Discorbis* species (Plates 7 & 8). This assemblage appears lower in the Pliocene sequence, below the Miliolid sequence. The southern beaches are dominated by *Elphidium* sp. (Plates 7 & 8), which prefer mobile water and rapid sedimentation at shallow depths.

The variety of foraminifera encountered in the present day Wardang Island sands is shown in Plates 7 & 8, and a taxonomic list appears as Appendix 13.

It should always be borne in mind that the present day beach sands represent a death assemblage. This may well vary from the actual life assemblage, as the empty tests of foraminifera are easily transported by tidal and other currents and/or wind, as exhibited by their inclusion in the aeolianite.

PLATE 7

a : *Marginopora vertebralis* x 10

b : *M. vertebralis* x 10

c : *Clavulina difformis* x 30

d : *Triloculina virgula* x 120

e : *T.rotunda* x 130

f : *T. striatotrigonula* x 50
(note small adhering *Discorbis dimidiatus*)

g : *T. tricarinata* x 120

h : *Miliammina fusca* x 130

i : *Cribrobulimina polystoma* x 30

j : *Vertebralina sriata* x 50

k : *Spirolina* sp. x 30

l : *Peneroplis planatus* x 30

m : *Scutuloris* sp. x 100

n : *Nubecularia lucifuga* x 70

o : *Spiroloculina antillarum* x 40

p : *S. angusteoralis* x 50

q : *Spirolina* sp. x 70

r : *Peneroplis pertusus* x 70

s : *Quinqueloculina tenagos* x 80.

A more detailed taxonomy appears in Appendix 13.

PLATE 7

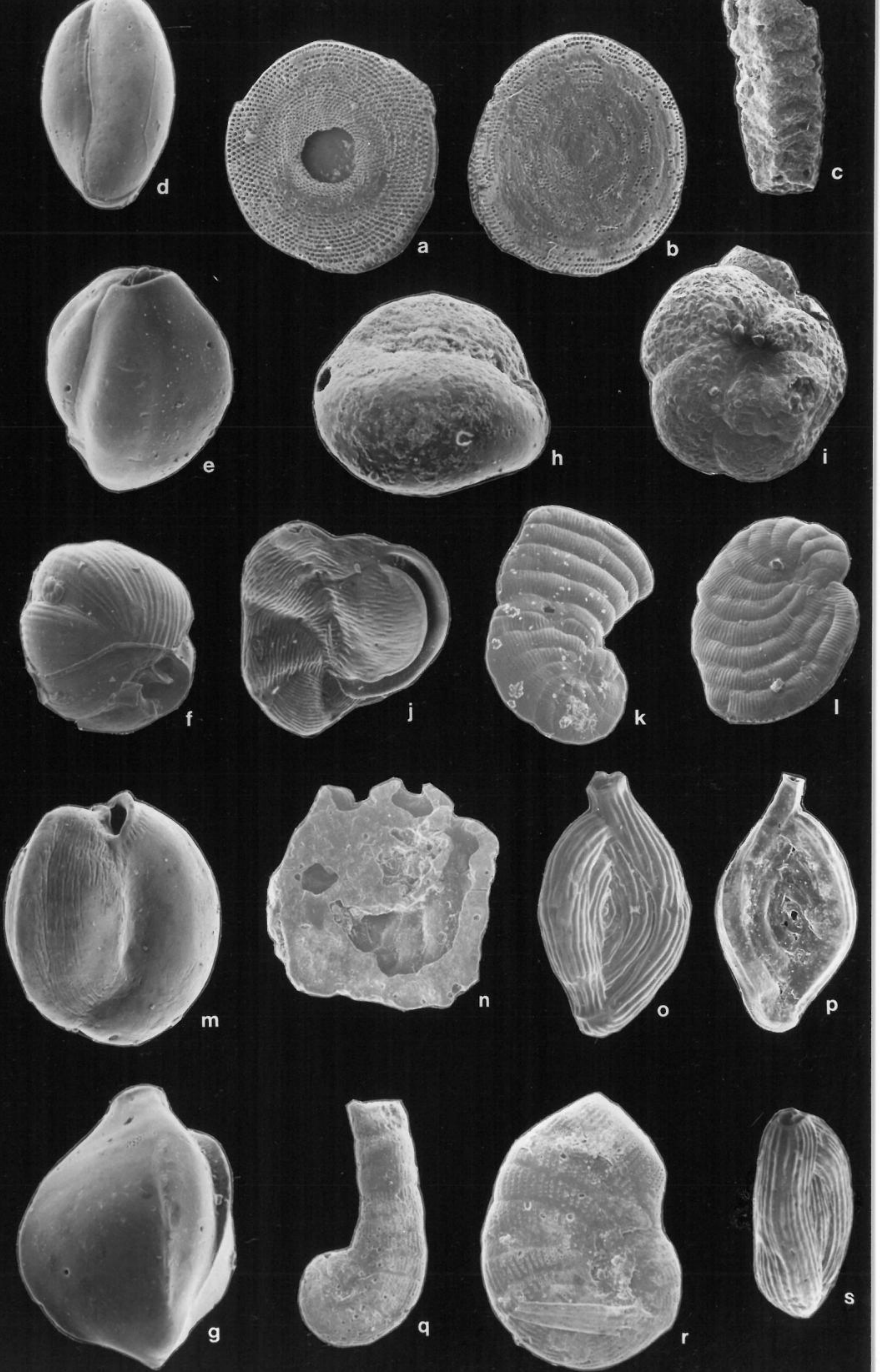


PLATE 8

RECENT FORAMINIFERA

a : *Elphidium pseudonodosum* x 90

b : *E. macellum* x 50

c : *E. crispum* x 60

d : *E. articulatum* x 100

e : *E. crispum* - juvenile x 60

f : *Fissurina orbignyana* x 150

g : *F. lucida* x 200

h : *F. marginata* x 80

i : *Polymorphina* sp. x 130

j : *Ammonia beccari* x 70

k : *Planorbulina mediterranensis* x 30

l : *Bolivina* sp. x 100

m : *Lagena distoma - margaritifera* x 100

n : *L. bassensis* x 150

o : *Brizalina striatula* x 100

p : *Patellina corugata* x 100

q : *Annulopatellina annularis* x 110

r : *Bolivinella folium* x 150

s : *Glabratella australensis* x 110

t : *Rosalina kennedyi* x 70

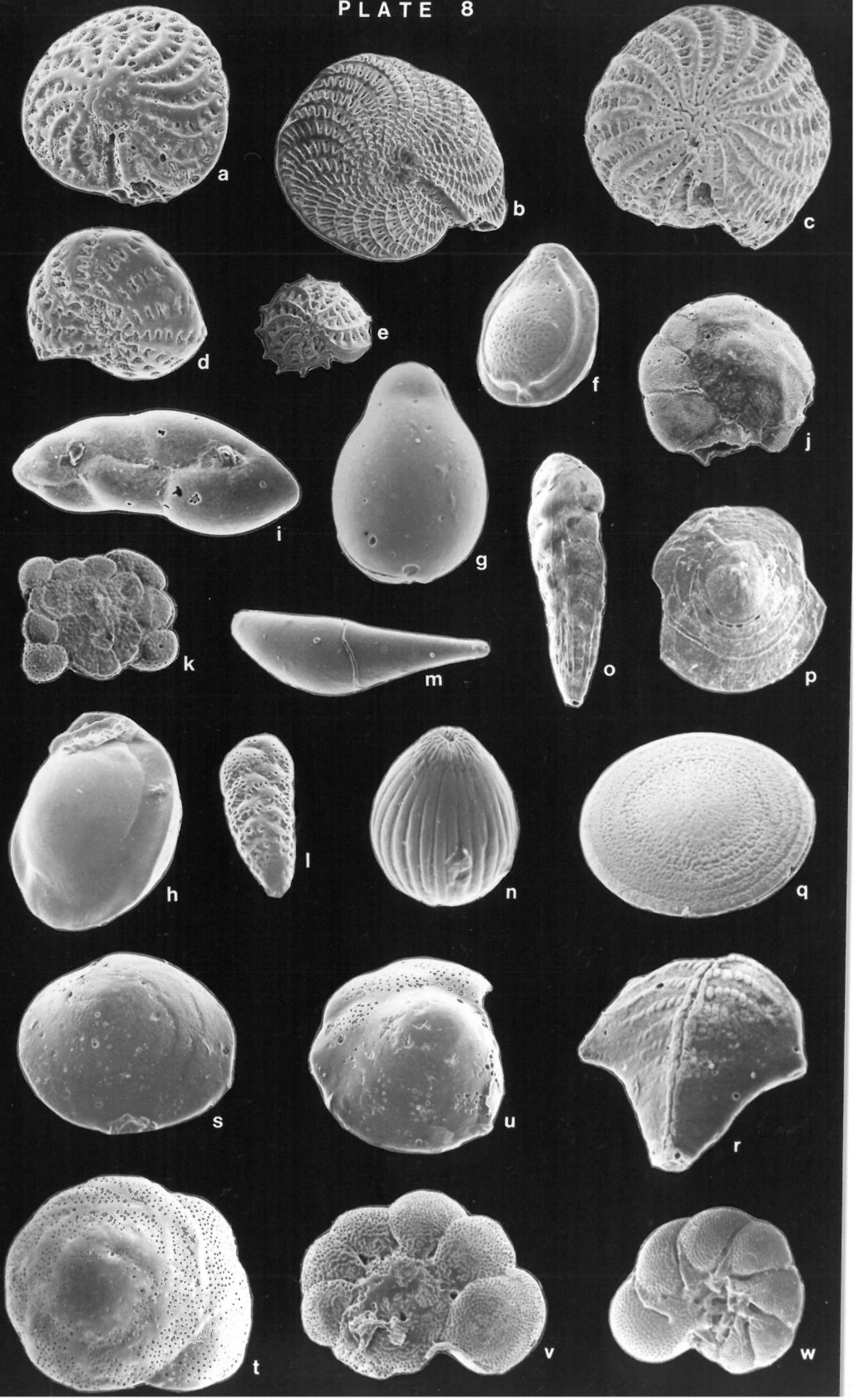
u : *Discorbis vesicularis* x 80

v : *D. dimidiatus* x 30

w : *D. dimidiatus* - ventral surface. x 30.

A more detailed taxonomy appears in Appendix 13.

PLATE 8



Marginopora vertebralis (Plate 7)

M. vertebralis is reputed to have become extinct following upon the deposition of the Glanville Formation in South Australia, although it still flourishes at Shark Bay (Logan et al. 1976) and along the Great Barrier Reef where water temperatures are much higher than in the Southern Ocean. On Wardang Island it occurs in the beach rock on the 2 m high stranded beaches, the stratigraphic age of which is probably Glanville Formation. However, it is also found as complete, uncemented individuals amongst the daily, tidally deposited detritus at the edge of the reef between Goose Island and Wardang. Microscopic observation of *M. vertebralis* from this site, the beach rock and the Pliocene from Wardang Island, Glanville Formation material from St. Kilda beach and recently living specimens from the Great Barrier Reef leads one to suspect that this organism may still be extant in the modern Wardang Island reef. The tests at the latter locality show no evidence of any cementation.

To test this hypothesis further, a comparative analysis of the Mg content of the tests was made (Appendix 14) (Table 7). The living organism secretes a high-Mg calcite test (Bathurst 1975), which after death and incorporation into the sediment, rapidly inverts to low-Mg calcite by diagenesis.

Chemical Analyses of $MgCO_3$ content of *Marginopora vertebralis*

Location	Age	$MgCO_3$%
Wardang Island (shore-line detritus)	possibly present	8.99
Great Barrier Reef	present	9.75
Wardang Island (beach rock)	younger than Glanville Formation	10.31
St. Kilda Beach	Glanville Formation	6.27
Wardang Island	Pliocene (Hallett Cove Sandstone)	3.35

TABLE 7

The analytical results further support the hypothesis, that this species is still extant around Wardang Island but do not prove it. It is desirable that a thorough search be made for the living organism in this area. The logistics of undertaking such a search were beyond the scope of this project, but the author intends to pursue this aspect shortly. Care will be needed as hasty decisions based on suggested protoplasm-staining techniques could be misleading, as various algae and bacteria are known to rapidly invade vacated tests.

Hand specimen and thin section descriptions appear in Appendix 11.

CONCLUSIONS & RECOMMENDATIONS

A new stratigraphic sequence to include the Permian can be erected for Wardang Island. Difficulty is still encountered, however, when subdividing the Quaternary.

The Basement consists of acid volcanics - namely porphyritic rhyo-dacite and latite, interbedded with minor conglomerates and metasediments. Sedimentary structures and geochemical data indicate the sequence youngs to the south. Although the major unit, the porphyritic rhyo-dacite, was probably erupted as an ash flow, no primary structures remain due to later metamorphic and tectonic modification.

It is likely that the major phase of these events was related to the Olarian orogeny. Detailed structural analyses may elucidate the similarities further. Geochemical analyses suggest a correlation exists between the Gawler Range Volcanics, the Moonta Porphyry and the Wardang Island acid volcanics. However, the age of 1735 $\pm$ 42 M.a. obtained on the porphyritic rhyo-dacite is highly unlikely to be a primary crystallization date, rather it is undoubtedly the date of the last re-setting event. As the unmetamorphosed Gawler Range Volcanics give a primary age of 1535 $\pm$ 25 M.a., it must be fortuitous that they have similar chemistries. The Moonta Porphyry, however, appears similar in metamorphic modification and its younger age may be due to a later re-setting event that did not affect Wardang Island sufficiently to cause re-setting. The complex trace element geochemistry leads to the postulation of magma derivation from a primitive mantle by a two or multi-stage process. The acid volcanics are intruded by amphibolite dykes of continental tholeiitic affinities.

Permian glacigene sediments unconformably overly the acid volcanics. Garnets and staurolites from the mottled clay till exhibit well-defined chattermark trails. Geochemical analyses indicate Cape Willoughby as the source of the largest erratic, indicating an ice movement direction of 340^{o}, correlating with the grooves on the exhumed Basement surfaces.

The richly fossiliferous Pliocene sequence is the equivalent of the Hallett Cove Sandstone. Macro- and micro-fossil evidence indicates a warmer temperature pertained during deposition of this sequence, but with a marked cooling towards the end of the Pliocene. A detailed taxonomic study of the macro-fossil assemblage could provide additional palaeoenvironmental and palaeoclimatological data.

Within the Quaternary, the allocation of the calcretes and aeolianites to exact stratigraphic time slots remains a problem. Stranded shingle beach ridges, aeolianite dunes and wave-cut platforms, calcreted undersea reefs, inland shell-hash deposits, calcretes and fossil soils and index fossils indicate sea-level changes that place some constraints on the dating of these events. Nevertheless, more detailed cross correlations are needed.

The presence of small, uncemented *M. vertebralis* specimens in the present day tidal detritus suggests this species may still be extant on the reef between Goose Island and Wardang Island. $MgCO_3$ analyses further support this hypothesis. However, the living organism should be found before concluding that the hypothesis is a fact.

These new 'facts' presented in this project are accompanied by Hoffman's (in Bathurst, 1975) pungent warning......."Yesterday's heresy is to-day's dogma, and the bandwagon effect makes adherents to the new..... paradigm easier to muster than proof".

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APPENDICES

APPENDIX 1

HAND SPECIMEN & THIN SECTION DESCRIPTIONS - PRECAMBRIAN

524-400 Porphyritic rhyo-dacite

Hand specimen: Dark pink-grey fine grained rock, with pink phenocrysts ($\leqslant$ 40.4 cm) of plagioclase. Weathered surfaces exhibit linear habit of mafics - biotite, chlorite and hornblende. No preferred cleavage or foliation direction.

524-401 Porphyritic rhyo-dacite.

Hand specimen: same as 524-400.

524-402 Porphyritic rhyo-dacite

Hand specimen: Similar to 524-400 - except very weathered (chemically). Phenocrysts altered to clays.

Thin section: Sericitized phenocrysts of plagioclase in recrystallised (and partly sericitized) matrix of microcline, plagioclase, quartz and biotite. Secondary carbonate present as inclusions in phenocrysts and as separate distinct grains. No fabric. Polygonal boundaries with triple point junctions

30% phenocrysts - sericite : plagioclase

70% matrix	60% K-feldspar
	20% quartz
	10% plagioclase (An 45-60)
	5% biotite
	2% carbonate/scapolite
	2% opaques
	1% accessory : sphene, zircon

524-404 Porphyritic rhyo-dacite

Hand specimen: same as 524-400.

Thin section: similar to -402. Phenocrysts almost entirely sericitized.

30% phenocrysts - plagioclase:sericite

70% matrix	40% K-feldspar	10% biotite
	30% quartz	2% carbonate
	10% plagioclase	2% opaques
	6% accessory: sphene, zircon, apatite, hornblende	

524-405 Porphyritic rhyo-dacite

Hand specimen: same as 524-400

Thin section : similar to -402. Phenocrysts up to 4 mms. no fabric, opaques associated with hornblende.

phenocrysts ≈ 50% total sericite/plagioclase
matrix - 50% K-feldspar (microcline)
- 25% quartz
- 5% plagioclase
- 5% hornblende
- 5% biotite
- 3% carbonate, zircon, apatite
- 2% opaques.

524-406 Porphyritic rhyo-dacite

Hand specimen: Similar to 524-400, biotite/chlorite shows marked orientation.

Thin section : similar to -402. Biotite is retrogressed to chlorite and shows tendency to being oriented.

phenocrysts ≈ 30% total sericite/plagioclase
matrix - 50% K-feldspar
- 15% quartz
- 20% biotite/chlorite
- 5% hornblende
- 5% plagioclase
- 2% carbonate, zircon, apatite
- 3% sulphides

524-408 Porphyritic rhyo-dacite

Hand specimen: same as 524-400

Thin section : similar to -402. Shows marked mineral fabric in biotite/hornblende. Phenocrysts at right angles to lineation, and have pressure shadows developed in direction of lineation. Carbonate absent, except as inclusions in phenocrysts.

phenocrysts. 25% of total sericite/plagioclase
matrix - 60% K-feldspar (sericite)
10% biotite
8% hornblende
8% quartz
4% plagioclase
8% opaques
2% accessory : carbonate, apatite, zircon.

524-409 (1) Porphyritic rhyo-dacite

Hand specimen: Similar to 524-400. Darker in colour. Felsic veins. Blebs of magnetite crystals.

Thin section : Foliation very well developed. Many phenocrysts are almost orthogonal to foliation, and show recrystallised areas (mainly microcline) in direction of foliation, due to recrystallisation in areas of less pressure, i.e. not true pressure shadows. Small recrystallised biotite crystals have sharp terminations and wrap around phenocrysts. Rare larger primary equant biotites have ragged margins. No carbonate.

phenocrysts ≈	30% of total	sericite/plagioclase
matrix	45%	K-feldspar
	10%	quartz
	5%	plagioclase
	20%	biotite
	15%	opaques
	5%	hornblende, apatite, zircon.

524-410 (1) Porphyritic rhyo-dacite

Hand specimen: Similar to 524-400. Well defined linear fabric exhibited by hornblende/biotite. Phenocrysts randomly orientated.

Thin section : Similar to 524-409 (1), but with foliation defined by large green hornblende aggregates, and very little biotite.

phenocrysts ≈	30% total	plagioclase/sericite
matrix	45%	K-feldspar (microcline)
	10%	quartz
	5%	plagioclase
	20%	hornblende
	15%	opaques
	5%	biotite and accessories.

524-410 (2) as above.

Hand specimen: Porphyritic rhyo-dacite.

Thin section: Weathered surface area. Approximately 40% of matrix altered to sericite. Little hornblende, but large biotites with ragged terminations. Phenocrysts have carbonate inclusions and large biotite and microclines.

524-410 (2) (cont'd)

phenocrysts ≈ 25% total. plagioclase/sericite
matrix 40% sericite
20% quartz
10% K-feldspar (microcline)
15% biotite
10% opaques
5% accessories + hornblende, carbonate

524-412 Porphyritic rhyo-dacite

Hand specimen: Similar to 524-400. Darker in colour.

Thin sections: Similar to 524-409. Biotites are smaller. Small carbonate inclusions in phenocrysts.

phenocrysts ≈ 30% total. plagioclase/sericite
matrix 40% K-feldspar (microcline)
25% quartz
10% plagioclase
10% biotite
10% opaques
5% accessories.

524-413 Pegmatite

Hand specimen: Vein-type pegmatite, with large plagioclase crystals.

Thin section : Vein material. Large (up to 1 cm) composite crystals, indicating recrystallisation. Quartz shows undulose extinction. Plagioclase is altered to sericite and contains minor carbonate inclusions. Grain boundaries embayed.
58% plagioclase/sericite
40% quartz
2% accessories

524-414 Amphibolite

Hand specimen: Dark-green, black coarse-grained (≤ 0.4 cm) rock with quartz veins. Dyke material. Predominantly hornblende.

Thin section : Recrystallised quartz vein areas with recrystallised plagioclase and minor sericitised plagioclase. The quartz shows undulose extinction and triple junctions. The hornblende (green) is bimodal in size and distribution, and is interspersed with quartz and plagioclase. No fabric.

524-414 (cont'd)

50% hornblende
35% quartz
10% plagioclase/sericite (An_{55})
5% opaques, biotite & K-feldspar

524-416 Calc-silicate

Hand specimen : 50% Felsic areas of calc-silicates, plagioclase and quartz and 50% mafic areas of hornblende/biotite. Appears to be carbonate/porphyry in dyke contact.

Thin section : Scapolite-rich rock, with hornblende blebs. Matrix consists of recrystallised rhyo-dacitic material. Scapolite probably formed by metasomatism with intrusion of adjacent dyke, which also introduced hornblende. Outlines of phenocrysts no longer discernible.

25% scapolite
25% hornblende
25% plagioclase/sericite
10% quartz
10% K-feldspar
5% opaques, accessories, e.g. carbonate.

524-417 Amphibolite

Hand specimen: Dark-green black coarse-grained dyke rock, predominantly hornblende, with minor plagioclase laths. No preferred orientation.

Thin section : Coarse grained re-crystallised amphibole, showing slight tendency to a foliation. Opaques associated with common sphene.

80% hornblende
8% plagioclase/sericite
5% sphene
2% biotite
2% opaques
2% quartz
1% accessories - scapolite.

524-418 Aplite vein

Hand specimen: Coarse grained vein material of buff-coloured plagioclase and minor quartz and K-feldspar.

Thin section : Vein material of sericitized plagioclase, with hornblende-rich blebs. No fabric.

524-418 (cont'd)

60% plagioclase/sericite
15% hornblende (adjacent dyke)
5% scapolite
10% K-feldspar
10% quartz

524-420 Porphyritic rhyo-dacite

Hand specimen: Same as 524-400

Thin section : Similar to 524-402. No carbonate.

40% Phenocrysts : plagioclase/sericite
60% Matrix -50% K-feldspar (microcline)
-25% quartz
-10% plagioclase
-10% biotite
- 2% hornblende
- 2% opaques
- 1% accessories - zircons, apatite, sphene.

524-421 Aplite vein

Hand specimen: Coarse-grained vein material of K-feldspar, scapolite, quartz and plagioclase.

Thin section : Recrystallised scaptolised mafic-depleted vein material. Triple junctions and seriate boundaries.

25% K-feldspar (microcline)
30% scapolite
20% quartz
25% plagioclase/sericite

524-426 Scapolite 'schist' (light coloured)

Hand specimen: Compact, fine grained and quartzose rock. Possibly metamorphosed carbonate.

Thin section : Fine grained and recrystallised. Boundaries of quartz are embayed. Scapolite appears as infilling material. Foliation poorly defined by biotite.

60% quartz
20% scapolite
18% biotite/chlorite
1% opaques
1% accessories

524-427 Scapolite 'schist'

Hand specimen: Similar to 524-426, except more micaceous and visible magnetite octahedra.

Thin section : Similar to 524-426, but well-defined foliation, delinated by both biotite and elongate crystals of scapolite.

30% quartz
30% scapolite
35% biotite/chlorite
4% opaques
1% accessories

524-428 Quartz

Hand specimen: Pure white, opaque quartz

Thin section : Coarse grained vein quartz showing undulose extinction.

524-433 Porphyritic rhyo-dacite

Hand specimen: Similar to 524-400. Epidote and mafic-rich 'veins'.

Thin section : Similar to 524-402, but with epidote common, plus scapolite.

phenocrysts	25% plagioclase/sericite
matrix 75%	25% K-feldspar
	20% quartz
	10% plagioclase
	10% epidote
	25% hornblende
	5% biotite
	2% opaques
	3% accessories

524-437 Conglomerate (Foreign Clast)

Hand specimen: Similar to 524-415. One foreign rounded clast of coarse grained aplite. Matrix wraps around clast (indicated by biotite orientation). Rhyo-dacite clasts show elongation.

Thin section: Clast consists of coarse grained predominantly felsic material, with minor biotite. Much of the K-feldspar is altering to myrmekite. No fabric.
The enclosing host material is finer grained rhyo-dacitic material, with good foliation defined by biotite and scapolite. It lacks phenocrysts. The foliation wraps around the clast.

524-437 (cont'd)

Clast:

45% quartz
45% K-feldspar (microcline)
5% plagioclase
3% biotite
2% scapolite & accessories

Matrix

50% K-feldspar
15% quartz
5% plagioclase
15% biotite
10% scapolite
5% opaques & accessories.

524-439 Conglomerate

Hand specimen : Similar to 524-415, but matrix is more mafic. Specimen shows elongation of clasts.

Thin section : (1) Clasts are fine re-crystallised felsic material, including phenocrysts, with little mafic or opaque material. Sharp boundaries. Matrix is mafic, opaque rich coarser recrystallised material with a well developed foliation delineated by biotite. This wraps around the clasts.

(2) Some larger grains of quartz and K-feldspar in clast material. Quartz shows undulose extinctions, seriate boundaries and triple point junctions.

Clasts

50% K-feldspar
40% quartz
10% plagioclase

Matrix

25% K-feldspar
25% plagioclase/sericite
10% quartz
25% biotite
10% opaques
5% hornblende, accessories.

524-440 Latite

Hand specimen: Dark grey fine-grained mafic rock with white phenocrysts of plagioclase. Areas with more biotite, but no preferred orientation.

Thin section: Mafic rich quartz depleted fine grained porphyritic volcanic. Two phases of biotite, with secondary smaller phase defining a foliation.

524-440 (cont'd)

25% phenocrysts	25% phenocrysts	plagioclase/sericite
70% matrix	50%	K-feldspar (microcline)
	25%	biotite
	15%	plagioclase
	5%	quartz
	4%	opaques
	1%	accessories

524-441 Conglomerate-metasediment.

Hand specimen : Similar to 524-415 and 524-422. Boundary between the two lithologies is quite distinct. Clasts are elongated orthogonally to boundary (S_o).

Thin section : Similar to 524-439.

524-442 (1) Altered dyke - metasediment

Hand specimen : Probably dyke intruded into metasediment with boundary showing intermixing effect. Well-defined hornblende lineation. Some epidote blebs. Metasediment contains phenocrysts.

Thin section : Well-foliated medium grained metasediment with mafic blebs of hornblende/scapolite. Foliation defined by fine-grained secondary hornblende and biotite.

(2) Similar, but more scapolite and opaques.

35% hornblende
35% K-feldspar (microcline)
10% quartz
10% plagioclase
5% biotite
4% scapolite
1% accessories and opaques.

524-443 Metasediment

Hand specimen : Quartzose 'schist' still showing primary bedding, but with biotite orientated orthogonally to S_o. Some thin bands contain very little mafic material. Scattered magnetite blebs.

Thin section (1) Section shows foliaton developed orthogonally to primary bedding. Foliation defined by chloritised biotite. Primary sedimentary material predominating. K-feldspar and plagioclase, with minor amphibole and scapolite.

524-443 (cont'd)

(2) Similar to (1), except bedding not shown.

(3) Similar to (2)

40% biotite/chlorite
25% K-feldspar (microcline)
20% plagioclase
10% hornblende
5% quartz
5% opaques, scapolite & accessories.

524-444 Metasediment

Hand specimen : Similar to 524-443, but with 'eyes' of more felsic material, rimmed by mafic layer.

Thin section : Similar to 524-443 (2), plus 0.5 cm rounded blebs of coarser material. No foliation within blebs.

40% biotite/chlorite
25% K-feldspar (microcline)
20% plagioclase
10% hornblende
5% quartz
5% opaques, scapolite & accessories.

524-446 Porphyritic rhyo-dacite

Hand specimen : Similar to 524-400, but has indistinct clast-like boundaries.

Thin section : Similar to 524-409, but with less phenocrysts.

20% phenocrysts :	20% plagioclase/sericite
80% matrix	45% K-feldspar (microcline)
	5% plagioclase
	10% quartz
	20% biotite
	15% opaques
	5% accessories

524-447 Porphyritic rhyo-dacite

Hand specimen : Same as 524-400.

Thin section : Similar to 524-402. No pressure shadow development. Minor hornblende.

30% phenocrysts :	30% plagioclase/sericite
70% matrix :	55% K-feldspar (microcline)
	20% quartz

524-447 (cont'd)

10% plagioclase
8% biotite
2% hornblende
2% carbonate/scapolite
2% opaques
1% accessories.

524-227 Quartz

Hand specimen : Vein quartz. Milky and fractured.

Thin section : Quartz - undulose extinction. Large grains with seriate boundaries. Minor large grains of microcline.

524-228 Quartz

Hand specimen : Same as 524-227

Thin section : Quartz - undulose extinction. Large composite grains, with individual grains very small, with seriate boundaries.

524-427 Pegmatite

Hand specimen : Large crystals of milky, fractured quartz and pink orthoclase.

Thin section : Similar to 524-227. Orthoclase shows simple twinning.

524-445 Quartz-Aplite

Hand specimen : Vein quartz as in 524-228, with medium grained aplite.

Thin section : Quartz same as in 524-228. Aplite consists of quartz, K-feldspar and less than 5% mafics.

524-601 Porphyritic rhyo-dacite

Hand specimen : A well developed microfabric is evident from the parallel orientation of elongate biotite. Relict phenocrysts of plagioclase, now heavily sericitized are set in a quartzo-feldspathic matrix.
No ophitic igneous texture is evident, the rock in general appears to have been recrystallized.

Thin section : 30% phenocrysts - plagioclase/sericite

: 16% quartz - in groundmass
70% matrix
10% plagioclase - relict phenocrysts, heavily sericitized

524-601 (cont'd)

	to the extent that muscovite is evident, some secondary carbonate formed,
	- pericline twinning
	- present in groundmass
5% biotite	- green brown to pale green pleochroism.
chlorite	- possible intergrowths with chlorite
5% carbonate/ scapolite	- present as inclusions in plagioclase and as separate distinct grains.
sphene	- associated with the opaques and as distinct separate grains,
1% muscovite	- also related to sericitization and carbonate replacement of plagioclase phenocrysts.
zircon	- common
2% opaques	- irregular, round common some have cores of sphene.

524-602 Porphyritic rhyo-dacite

Hand specimen : Similar to 524-601

Thin section : have poikilitic hornblende and biotite. Sphene can be seen to be replacing the opaques.

524-603 Porphyritic rhyo-dacite

Hand specimen : same as 524-602

Thin section : more hd than in 524-602, can see carbonate association with poikilitic hornblende. Biotite has a more random orientation.

524-604 Porphyritic rhyo-dacite

Hand specimen : same as 524-601.

Thin section : Similar to 524-601. Hornblende is rare or absent, tend to have a biotite chlorite assemblage.
Biotite is well orientated. Sphene replacing opaques.
Muscovite as discrete grains. Apatite present.

524-605 Porphyritic rhyo-dacite

Hand specimen : Same as 524-601.

Thin section : Similar to 524-601, Hornblende is rare or absent.

524-606 Porphyritic rhyo-dacite

Hand specimen : Same as for 524-601.

Thin section : Similar to 524-601.

524-606 (cont'd)

Hornblende is rare. Biotite not as prevalent as other slides. Biotite tending to be finer grained than usual with only a few scattered coarser grains

524-607 Porphyritic Rhyo-dacite

Hand specimen : Same as 524-601

Thin section : Very similar to the first set of samples, no hornblende, perhaps a little more chlorite replacing biotite, plus epidote.
All the plagioclase phenocrysts appear to have been replaced by sericite and epidote. Carbonate absent.

524-608 Porphyritic Rhyo-dacite

Hand specimen : Same as 524-601

Thin section : Very similar to the first set of samples, no hornblende, perhaps a little more chlorite replacing biotite, plus epidote.
All the plagioclase phenocrysts appear to have been replaced by sericite and epidote. Carbonate absent.

524-609 Porphyritic Rhyo-dacite

Hand specimen : Same as 524-601

Thin section : Very similar to the first set of samples, no hornblende, perhaps a little more chlorite replacing biotite, plus epidote.
All the plagioclase phenocrysts appear to have been replaced by sericite and epidote. Carbonate absent.

524-610 Porphyritic Rhyo-dacite

Hand specimen : Same as 524-601

Thin section : Very similar to the first set of samples, no hornblende, perhaps a little more chlorite replacing biotite, plus epidote.
All the plagioclase phenocrysts appear to have been replaced by sericite and epidote. Carbonate absent.

524-611 Porphyritic Rhyo-dacite

Hand specimen : Similar to 524-601, but with a thin epidote vein continuous the length of the specimen.

Thin section : Similar to 524-601, but with epidote present.

524-613 Porphyritic Rhyo-dacite

Hand specimen : Similar to 524-601, but with a thin epidote vein continuous the length of the specimen.

Thin section : Similar to 524-601, but with epidote present.

524-614 Porphyritic rhyo-dacite

Hand specimen : A well developed microfabric is evident from the parallel orientation of elongate biotite. Relict phenocrysts of plagioclase, now heavily sericitized are set in a quartzo-feldspathic matrix.
No ophitic igneous texture is evident, the rock in general appears to have been recrystallized.

Thin section : Similar to 524-601.
Carbonate present.
Have one very coarse grain of an opaque. Generally seen to have more areas of the intermediate grainsizes, slightly less biotite and hence less of the well developed fabric. The groundmass seems to be slightly coarser.

524-615 Porphyritic rhyo-dacite

Hand specimen : A well developed microfabric is evident from the parallel orientation of elongate biotite. Relict phenocrysts of plagioclase, now heavily sericitized are set in a quartzo-feldspathic matrix.
No ophitic igneous texture is evident, the rock in general appears to have been recrystallized.

Thin section : Similar to 524-601.
Carbonate is present, the comments made about grainsize for sample 524-614 apply. Chlorite is abundant to the excess of biotite.

524-620 Moonta Porphyry (drill core sample)

Hand specimen : Fine grained dark pink and dark grey porphyritic rock.
Pink phenocrysts are plagioclase. No preferred mineral orientation. Mafic-rich blebs (approx. 0.3 cm long). 1 cm diameter bleb of chalcopyrite.

524-620 (cont'd)

Thin section : Similar to 524-402. No carbonate or scapolite. No pressure shadow development. No lineation.

20% phenocrysts	: plagioclase/siricite (An_{45-60})
80% matrix	: 55% K-feldspar
	10% quartz
	10% plagioclase
	5% biotite
	15% hornblende
	3% opaques
	2% accessory : sphene, zircon.

524-403 Porphyritic rhyo-dacite

Hand specimen : Similar to 524-400. Segregations of more felsic blebs with higher phenocryst content.

524-407 Porphyritic rhyo-dacite

Hand specimen : same as 524-400

524-411 Porphyritic rhyo-dacite

Hand specimen : Similar to 524-400. Stictolithic vein development. Mafics lineated. Lighter in colour.

524-415 Conglomerate

Hand specimen : Rounded clasts of light coloured porphyritic rhyo-dacite in darker (more mafic) matrix. Minor mafic clasts, with large magnetite octahedra. Marked linear orientation of mafics.

524-419 Porphyritic rhyo-dacite

Similar to 524-400.
Brick-red coloured. Little mafics.

524-422 Metasediment

Hand specimen : Schistose, layered medium grained rock, with felsic layers that could be derived from rhyo-dacite. Grey coloured.

524-423 Conglomerate

Hand specimen : Rounded clasts of light coloured porphyritic rhyo-dacite in hornblende-rich matrix. No lineation.

524-424 Conglomerate

Hand specimen : same as 524-415.

524-425 Conglomerate

Hand specimen : same as 524-415

524-429 Porphyritic rhyo-dacite

Hand specimen : Similar to 524-400. Two zones of different coloured matrix, separated by thin felsic vein.

524-434 Porphyritic rhyo-dacite

Hand specimen : same as 524-433.

524-435 Porphyritic rhyo-dacite

Hand specimen : similar to 524-400. Stictolithic vein development.

524-436 Conglomerate

Hand specimen : same as 524-415

524-438 Conglomerate (with foreign clast)

Hand specimen : same as 524-437. Foreign clast is approx. 10 cms. in diameter.

APPENDIX 2 STAINING - K-feldspar

Wash thin section or rock specimen in warm water and detergent. Place face down over container of HF acid i.e. in fumes, for 1 minute. Place in bath of sodium cobaltinitrite (3.3 gms in 5 mls of water) for 2-3 minutes. Wash.
K-feldspar stains bright yellow.

APPENDIX 3 ANALYTICAL TECHNIQUES

1. Sample Preparation

The sample preparation procedure was as follows:

(a) Weathered surfaces were trimmed from the rocks before crushing with a small Jaw Crusher.

(b) The crushed sample was ground to approximately 200 # particle size, using a Siebtechnik chrome steel mill.

(c) Approx. 30g samples were ignited to 900°C for 12 hrs. to determine the percentage loss of volatiles (e.g. H_2O and CO_2).

(d) 280 mg of ignited powder was weighed out with 20 mg of sodium nitrate and 1.5 g of lithium fluoride flux (batch 13). This powder was fused into buttons for whole rock analyses using the X-R-F technique.

(e) Approx. 8 g of rock powder was used to make pressed buttons for trace element determinations.

2. Analytical Methods

(a) Na_2O Determinations

Samples of ignited powder of known weight (approx. 30 mg.) were digested in a solution of H_2SO_4/HF = 1/5 in teflon beakers. Digested samples were diluted and made up to 100 ml. volumes. Sodium determinations were made using flame photometry. Analyses are accurate to within 1.1% (determined using Blackhill Norite 11 standard).

(b) Whole Rock Analyses

Whole Rock Analyses were determined by X.R.F. using the programmable Siemens S.R.S machine.

(c) Sc, Th Analyses

All analyses were determined during one program using the Siemens S.R.S X.R.F. machine.

(d) Zr Analyses

Determined using the Philips X.R.F. machine with the following operating conditions:

(1) Gold tube 50 kV 40 mA
(2) LiF_{220} crystal
(3) Scintillation counter
(4) Fine collimator
(5) Eht 355.

Lines measured:	Counting time:	Angle:
(1) Zr Kα	2 x 40 secs.	31.89°
(2) Zr, Sr background	"	32.89°
(3) Sr Kα	"	35.64°
(4) Th background	"	36.43°
(5) Th Kα	"	39.03°

Counting standard was: 331/371.

International standards were: BCR1, JG-1, GSP1.

(e) Nb Analyses

Determined using the Philips X.R.F. machine with the following operating conditions:

(1) Gold tube 50 kV 40 mA

(2) LiF_{220} crystal

(3) Scintillation counter

(4) Fine collimator

(5) Eht 348.

Lines measured:	Counting time:	Angle
(1) Nb background	2 x 40 secs.	29.62°
(2) Nb Kα	"	30.22°
(3) U background	"	36.40°
(4) U Kα	"	37.11°

Counting standard was 331/371.

International standards were: BCR1, JG-1, GSP1.

(f) Rb,Sr Analyses

Determined using the Philips X.R.F. machine with the following operating conditions:

(1) Molybdenum tube 60 kV 40 mA

(2) LiF_{220} crystal

(3) Scintillation counter

(4) Fine collimator

(5) Eht 358

Lines measured:	Counting time:	Angle:
(1) Y Kα	2 x 40 secs.	33.68°
(2) Y background	"	34.68°
(3) Rb Kα	"	37.78°
(4) Rb, Th background	"	38.42°
(5) Th Lβ	"	39.05°

Counting standard was MBM + BLC + Y

International standards were GSP-1, G2(4)

(g) Y Analyses

Determined using the Philips X.R.F. machine with the following operating conditions:

(1) Molybdenum tube 60 kV 40 mA

(2) LiF_{220} crystal

(3) Scintillation counter

(4) Fine collimator

(5) Eht 358

Lines measured:	Counting time:	Angle:
(1) Y Kα	2 x 40 secs.	33.68°
(2) Y background	"	34.68°
(3) Rb Kα	"	37.78°
(4) Rb, Th background	"	38.42°
(5) Th Lβ	"	39.05°

Counting standard was MBM + BLC + Y

International standards were GSP-1, G2(4)

(h) Ba, Ti Analyses

Determined using the Philips X.R.F. machine with the following operating conditions:

(1) Chromium tube

(2) LiF_{200} crystal

(3) Flow proportional counter

(4) Coarse collimator

(5) Eht 364

(6) Vacuum

Lines measured:	Counting time:	Angle:
(1) Ti Kα	2 x 40 secs.	86.20°
(2) Ba Lα	"	87.22°
(3) Ba Lα + 1° → background	"	88.22°

Counting standard was VHG + Ba + Sc

International standards were MRG-1, GH, G2

(i) Ce,Nd Analyses

Determined using the Philips X.R.F. machine with the following operating conditions:

(1) Tungsten tube 60 kV 40 mA

(2) LiF_{200} crystal

(3) Flow proportional counter

(4) Coarse collimator

(5) Eht 368

(6) Vacuum

Lines measured:	Counting time:	Angle:
(1) Ce background	100 secs.	110.42^{o}
(2) Ce Lβ	"	111.63^{o}
(3) Nd Lα	"	112.67^{o}
(4) Nd background	"	113.87^{o}

Counting standard was G2

International standards were BCR-1, 482/4.

PLATE 10

PERMIAN

1. Exhumed Basement showing roche moutonées at Cliff Pt.
2. 524-058. Striated and faceted metaquartzite erratic.
3. Trench dug into mottled clay to obtain uncontaminated samples. Till is unconformably overlain by *Anodontia* horizon of Pliocene. Cliff Pt.

PLIOCENE

4. Quartz vein in *Anodontia* containing Pliocene conglomerate. Location O, (Fig. 1).
5. Fossiliferous Pliocene. *Anodontia* is dominant bivalve. Cliff Pt.
6. 524-205. Lowermost *Anodontia* horizon, showing foraminifera *Cribrobulimina* sp., Rotaliids and Miliolids and coralline algae. Micrite matrix. Plane light x 30.
7. 524-205. Well-preserved perforate test of a Rotaliid foraminifera, which shows pseudo-geopetal structure - neomorphic spar developing from micrite. Plane light. x 17.

QUATERNARY

8. Beach rock with calcrete capping. South of Bird Pt.

PLATE 10

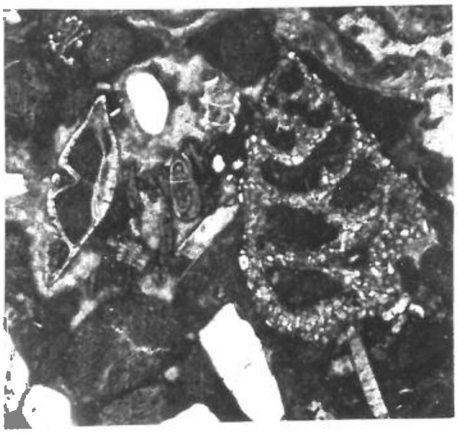

1


2


4


3


5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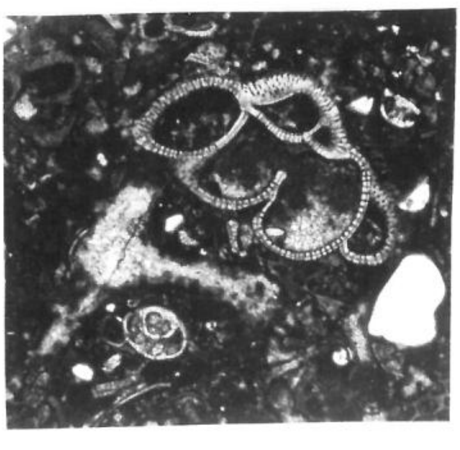
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APPENDIX 5

HAND SPECIMEN & THIN SECTION DESCRIPTIONS - PERMIAN

524-001 Quartz arenite (tillite)

Hand specimen : Medium grained buff coloured quartz arenite containing erratics of various sizes, shapes and lithologies. No bedding shown. Staining shows ferroan dolomite present as cement.

Thin section : 52% quartz : moderately sorted and rounded.
5% plagioclase: moderately rounded, medium sized.
1% garnets, staurolites and opaques.
1% hornblende.
30% matrix - clays (8%) ferroan dolomite (22%)
clay is very fine grained
ferroan dolomite secondary rhombohedral crystals, some zoned.
10% lithoclasts : metaquartzite.
1% accessories - microcline, sulphides.

524-003 Quartz arenite (tillite)

Hand specimen : Similar to 524-001, but contains limonite pseudomorph after pyrite (approx. 4 cms diameter).

Thin section : Similar to 524-001, but quartz is poorly rounded and matrix is more clay rich.

524-029 Hornfels erratic

Hand specimen : Light coloured banded rock, with layers of felsic material and thinner mafic bands.

Thin section : Mafic layers are predominantly hornblende. Felsic material is 70% quartz and 30% plagioclase/clays (sericite/kaolin.

524-030 Encounter Bay Granite Erratic

Hand specimen : Coarse-grained granite with the characteristic blue quartz of the Encounter Bay Granite suite. Biotite grains are coarse.

Thin section : 35% - K-feldspar - predominantly microcline, sericitized.
25% - quartz - undulose extinction - many grains recrystallised to smaller grain size.
25% - biotite - large brown flakes, with opaque inclusions.
10% - plagioclase - oscillatory zoning. Sericitized.
5% - accessories - hornblende, opaques.

524-031 Red Granite

Hand specimen : Coarse-grained red granite, with minor mafics. Feldspars show simple twinning.

Thin section : 60% - K-feldspar - microcline; sericitized.
30% - quartz - undulose extinction.
6% - plagioclase.
2% - biotite
2% - accessories - opaques, hornblende, zircon, apatite.

524-032 Hornfels Erratic

Hand specimen : Similar to 524-029, but not banded. Schistose.

Thin section : 50% - feldspars - mainly sericitised.
25% - quartz.
25% - biotite.

524-033 Porphyry Erratic

Hand specimen : Pink and green coloured feldspar phenocrysts in pink coloured matrix. Mafic rich blebs exhibit tendency to orientation. Not Wardang Island porphyritic rhyo-dacite, but very similar.

Thin section : 30% phenocrysts - plagioclase/sericite
70% matrix - 30% hornblende
- 20% biotite - lineated
- 30% K-feldspar (microcline)
- 10% quartz
- 5% plagioclase
- 3% opaques
- 2% accessories.

524-034 Quartz arenite (tillite)

Hand specimen : Same as 524-001 Base of outcrop.

Thin section : Similar to 524-001. Quartz grains are poorly sorted and poorly rounded, with very few grain to grain contacts, i.e. matrix supported. Matrix is predominantly ferroan dolomite. Minor garnets and staurolites.

524-035 Quartz arenite (tillite)

Hand specimen : Similar to 524-001. Middle of outcrop. No bedding, but lenses of fine-grained, clay rich material. Manganese dendrites common. Minor lithoclasts.

Thin section : Quartz grains are smaller than in 524-034 and poorly sorted and poorly rounded, but with grain to grain contacts in

524-035 (cont'd)

patches. Matrix is 50% clay and 50% ferroan dolomite. Minor large muscovite grains, garnets and staurolites are present.

524-036 Quartz arenite (tillite)

Hand specimen : Top of outcrop. Similar to 524-035. No bedding as such, but is stratified from very fine sand size to coarse sand size uneven layers. Manganese dendrites are common.

Thin section : Similar to 524-034.

524-038 Kaolinite (tillite)

Hand specimen : Specimen is from unconformity surface. Cream coloured, very fine soft but indurated clay. Contains very weathered limonite pseudomorph. Small blebs of coarse sandstone.

Thin section : Minor quartz, as in 524-034. Predominantly clay (probably kaolin), with some ferroan dolomite. Matrix.

524-039 Granite Erratic

Hand specimen : Granite erratic protrudes from unconformity surface into Pliocene. Its outer surface is very weathered, with the outer 1 cm being devoid of biotite and the feldspars altered to kaolin. Two feldspars, grey quartz, biotite, hornblende and tourmaline present.

Thin section : Typical granite, with orthoclase > plagioclase, 25% quartz, 20% mafics plus opaques and accessories.

524-051 Limonite Pseudomorph

Hand specimen : Specimen is from within quartz arenite (tillite). No evidence of pyrite apparent. Boundary is irregular. White quartz grains clearly visible within dark-red-brown limonite nodule, which is 4 cms in diameter.

Thin section : Specimen consists of poorly sorted and poorly rounded quartz grains 'floating' in a limonite matrix. Minor plagioclase, microcline and lithoclast particles present.

524-002 Quartz arenite (tillite)

Hand specimen : Similar to 524-035. Numerous manganese dendrites. Limonite pseudomorphs have pyritic cores.

524-004 Quartzite erratic

Hand specimen : Grey coloured quartzite pebble from within quartz arenite.

524-005 Granite erratic

Hand specimen : Megacrystic granite, with pink orthoclase, quartz, biotite and minor plagioclase.

524-006 Grey-chocolate-brown clay (till)

Hand specimen : Clay from unconformity surface with overlying *Anodontia sphericula* horizon of the Pliocene - at top of trench. Clay contains abundant gypsum crystals and plates. The clay is compact and can be removed in large, damp blocks, but dries out and crumbles rapidly upon exposure. No bedding, but distinctive mottled appearance. Numerous erratics. No fossils.

524-006A	top grey-chocolate-brown clay (till) Trench .
524-007	3 cms from top
524-008	30 " " "
524-009	30 " " "
524-010	48 " " "
524-011	82 " " "
524-012	122 " " "
524-013	139 " " "
524-014	176 " " "
524-015	221 " " "
524-016	243 " " "
524-017	275 " " "
524-018	275 " " "
524-019	288 " " "
524-020	305 " " "
524-023	330 " " "
524-024	350 " " "
524-025	compact clay
524-026	clay with linear streak of yellow clay
524-027	very dark brown clay - palaeontology sample
524-040	gypsum plates (7 cm x 6 cm x 1.5 cm) from within clay
524-041	Mn rich clay (black) - base of trench
524-042	" " " " - 25 cms above base of trench
524-043	" " " " - 38 " " " " "
524-044	" " " " - 50 " " " " "
524-045	" " " " - 68 " " " " "
524-047	palaeontology sample - base of trench
524-048	" " - 25 cms above base of trench
524-049	" " - 50 " " " " "
524-050	" " - 75 " " " " "

524-021 Granite Erratic

Hand specimen : Megacrystic pink granite. Large phenocrysts of pink orthoclase, quartz, minor plagioclase and biotite.

524-028 Granite Erratic

Hand specimen : Characteristic blue quartz containing Encounter Bay type granite.

524-037 Quartz arenite (tillite)

Hand specimen : Similar to 524-035, but with more Mn.

524-046 Erratic

Hand specimen : Erratic is from within clay, 50 cms from base of trench. It is coated with a thin smear of clay, which shows slickenside-like markings. This veneer has not been disturbed, so that lithology of rock is unknown.

524-052 Quartz arenite (tillite)

Hand specimen : Same as 524-035.

524-053 Quartz arenite (tillite)

Hand specimen : Similar to 524-035, but with quartz grains up to granule size.

524-054 Kaolinite (tillite)

Hand specimen : Similar to 524-038, but no limonite. Specimen, after being left undisturbed in plastic bag for 5 months, was encrusted with discrete and clumped needle-like crystals of gypsum, projecting $\leqslant$ 2.5 mms from the surface.

524-055 Quartz arenite (tillite)

Hand specimen : Similar to 524-034, but coarser. Numerous small granules and pebbles, pyrite grains, numerous garnets. Centre is unweathered and grey coloured, surrounded by brown-yellow sandstone.

524-056 Heavy-mineral Sand

Hand specimen : Sand has a high heavy mineral (garnet, staurolite, ilmenite and magnetite) content. It has formed a placer type deposit due to favourable physical conditions operating, and is similar to those formed at Petrel Cove. The heavy minerals have been derived from the glacigene sediments, as microscopic scanning revealed at least 50% of garnet grain surfaces had well-defined chattermark trails. If the minerals resulted from the weathering of the ubiquitous erratics, there would not be this high rate.

524-057 Quartzite erratic

Hand specimen : This erratic is faceted and striated - unequivocal evidence for its glacial transport.

APPENDIX 6

MODIFIED STAINING TECHNIQUE FOR CARBONATES

Procedure		Time	Carbonate	Result
Stage I	Etching 1.5% HCl	40-45 secs.	Calcite Ferroan calcite	Considerable etch
			Dolomite Ferroan dolomite	Negligible etch
Stage II	Staining		Calcite	Very pale pink-red depending on optical orientation.
	0.2g Alizarin red S per 100 c.c. of 1.5% HCl 2.0 g Potassium ferricyanide per 100 c.c. of 1.5% HCl	30-45 secs.	Ferroan Calcite	Very pale pink-red Pale blue - dark blue Two superimposed give mauve-purple-royal blue.
	Mixed in ratio 3:2		Dolomite	No colour
			Ferroan dolomite	Pale - deep turquoise depending on ferrous content.
Stage III	Staining 0.2 g Alizarin red S per 100 c.c. of 1.5% HCl	40-45 secs.	Calcite Ferroan calcite	Very pale pink-red
			Dolomite Ferroan dolomite	No colour

APPENDIX 7

PREPARATION OF PERMIAN GLACIGENE SEDIMENTS FOR FORAMINIFERA SEARCH

Approximately 200 g of unconsolidated mottled clay was placed in top sieve of sieve set (with bottom pan removed). Material was washed through thoroughly to remove fine clays and residues retained. Residue was placed in beaker and water added. Soniprobe was used to further disaggregate particles. Beaker was then placed on hot plate, sodium bicarbonate added, and boiled for 10 minutes. After cooling, material was resieved, with residue being collected and dried. This material was then scanned.

APPENDIX 8

PREPARATION OF SAMPLES FOR CHATTERMARK TRAIL SCANNING

Samples of glacigene sediments were disaggregated and sieved. The fraction between 150 and 75 μm was placed in S-tetrabromoethane (S.G. = 2.964) in a separating funnel and the heavy fraction (minerals) withdrawn. The heavy minerals were washed several times and dried. Hand picking under x10 magnification was done in order to separate garnets and staurolites. Some of the garnets and staurolites were mounted on slides using Eukitt. Scanning was done under a petrographic microscope at x400 magnification. Other garnets and staurolites were mounted on S.E.M. stubs, coated with gold and scanned using the S.E.M.

APPENDIX 9

ROCK SPECIMEN & THIN SECTION DESCRIPTIONS - PLIOCENE

Calcite cement unless otherwise stated.

524-203 Fossiliferous Limestone

Hand specimen: Top of Pliocene Section - probably lagoonal estuarine environment. Specimen has visible quartz grains and also appears to be partly calcretized. Fossils consist of *Turritella* sp. and many mollusc fragments. High porosity - buff coloured.

Thin section : Calcrete boundary is transitional and indicates in situ calcretization is occurring. Foraminifera present include *M. vertebralis, Discorbis* sp, *Elphidium* sp, and dominated by *Triloculina - Quinqueloculina* sp. The matrix consists of both blocky spar, neomorphic spar and micrite. Minor geopetal features. 3% embayed quartz grains. 2% of lithoskels are algae.

524-204 Fossiliferous Limestone

Hand specimen: Similar to 524-203. Poorly fossiliferous - one *Turritella* sp. Compact, except for calcite veins which have large voids. Light cream colour. Quartz grains visible.

Thin section : Foraminifera are being dissolved. Minor *Discorbis* sp. present, many *Triloculina - Quinqueloculina* sp. Dominant bioclasts are fragments of molluscs. Minor coralline algae. Matrix is both micrite and spar.

524-205 Fossiliferous Limestone

Hand specimen: Richly fossiliferous, with original shell preserved. Shows cross section of shell of *Cerithium potamides*, with laminar layers preserved and showing evidence of boring sponge (*Cliona* sp.) activity. The boring holes are infilled with limestone. Many fragments of bivalves remain. High quartz grain content and some calcretization apparent.

Thin section : 40% quartz - highly embayed; minor plagioclase and microcline grains. Matrix is mainly micrite, with some neomorphic spar. Foraminifera prolific - *Cribrobulimina* sp, *Elphidium* sp, *Peneroplis* sp, *Discorbis* sp, *Triloculina-Quinqueloculina* sp. Coralline algae represent 50% of microbioclasts. Bryozoa, echinoid fragments and molluscs also present.

524-209 *Cerithium potamides*

Hand specimen: Similar to 524-205. Contains large fossil fragments of *C. potamides*. Boring holes not all infilled.

Thin section : Same as 524-205.

524-210 Calcareous sandstone

Hand specimen: Coarse grained sandstone with calcareous cement (ferroan dolomite). No macro fossils. Basal Pliocene.

Thin section : 50% quartz clasts - poorly sorted and poorly rounded. Few grain to grain contacts. Matrix (35%) consists of very fine spar. Bioclasts are coralline algae and foraminifera (unidentifiable). Minor garnet grains.

524-211 Fossiliferous limestone

Hand specimen: Very porous, sandy limestone from echinoid horizon. Irregular echinoid probably *Micraster* sp. Many specimens of *M. vertebralis*. Ferroan dolomite cement.

Thin section : 35% quartz clasts, moderately rounded and sorted. Matrix supported. Matrix is fine spar. Foraminifera rich (approx. 35%) - dominated by Miliolids and *M. vertebralis*. Minor mollusc fragments and very few echinoid fragments. 5% coralline algae.

524-213 Fossiliferous limestone

Hand specimen: Similar to 524-203, but with greater variety of macro fossils, including *Meretrix* sp. Aragonite of mollusc shells has dissolved, leaving unfilled and partly filled voids. Top of Pliocene.

Thin section : Bivalve shows aragonite dissolution followed by equant spar infilling. Calcretization is occurring adjacent to bivalve and shows engulfment of bioclasts. The rich foraminifera population is dominated by Miliolids. 5% rounded quartz grains. 5% coralline algae. Minor bryozoa.

524-214 Fossiliferous Limestone

Hand specimen: Gastropod rich sandy limestone from upper part of Pliocene (? Pleistocene). External moulds only of many gastropods.

Thin section : Many of the gastropods show preservation of organic rim by micrite, with bladed spar infilling cavity of previous aragonitic shell. No geopetal features. Foraminifera rich - almost

524-214 (cont'd)

exclusively Miliolids. Minor quartz grains, coralline algae, echinoid fragments and bryozoa. Primary cement is micrite.

524-215 Fossiliferous Limestone

Hand specimen: Transitional with calcrete. 'Open' porosity due to dissolution of mollusc shells. Visible quartz grains.

Thin section : Calcretization has almost obliterated fossils - leaving small nodules of fossiliferous material. 5% rounded quartz grains, each rimmed with equant spar. Veinlets of spar.

524-218 Calcreted Pliocene

Hand specimen: Calcrete nodule with small relict Pliocene nodules in the core. Laminar calcrete deposited around large nodule. Laminae different colours. Also appear to be black nuclei.

Thin section : Predominantly micritic calcrete. Few fossils remain - indistinct outlines of foraminifera and one bryozoa. Veinlets of spar.

524-219 Calcreted Pliocene

Hand specimen: Similar to 524-218. Some nuclei appear to be very weathered porphyry.

Thin section : Similar to 524-218. Nuclei of porphyry. Fossil boundaries even more blurred.

524-431 Haematite

Hand specimen: Haematite (cherry-red streak) from ferruginised horizon. Massive.

Thin section : High component of basement material, which is finely brecciated. All grains coated with haematite and also stringers of haematite. Minor carbonate.

524-220 Calcareous sandstone

Hand specimen: Same as 524-210. Base of Pliocene Section. Ferroan dolomite cement.

Thin section : Similar to 524-210, except 70% clasts.

524-221 Calcareous sandstone

Hand specimen: Coarse grained, with slight bedding shown by some beds being more firmly cemented (ferroan dolomite cement). Similar to 524-210. 15 cms above unconformity - Pliocene section.

Thin section : Same as 524-210.

524-222 Sandy Fossiliferous Limestone

Hand specimen: Same as 524-211.

Thin section : Same as 524-211.

524-225 Basal Conglomerate

Hand specimen: Pliocene calcareous conglomerate, with clasts of basement porphyritic rhyo-dacite. Mollusc fragments common. Quartz clasts variable in size - up to 1 cm.

Thin section : Rhyo-dacite clast is ferruginised. Pliocene is richly fossiliferous - 50% bioclasts are coralline algae, 30% foraminifera - 20% Molluscs, echinoid fragments and bryozoa.- 50% quartz grains (feldspars) are well rounded.

524-200 *Anodontia sphericula*

Hand specimen: Internal mould and portion of original shell. Hinge line absent. Bivalve. Globular in shape.

524-202 *A. sphericula*

Hand specimen: Similar to 524-200, but complete (8 cms x 9 cms x 4.5 cms). Hinge line indicates affinity to Lucinidae. Shell is dissolving and recrystallising as calcite. Mn dendrites visible.

524-206 *C. potamides*

Hand specimen: Similar to 524-209. Contains well preserved specimen of *Macroclanculus* sp.

524-207 Fossiliferous limestone

Hand specimen: Sandy, bioturbated limestone with echinoids ($\leqslant$ 1.5 cms), probably *Micraster* sp. Large *M. vertebralis* specimens present.

524-208 Fossiliferous limestone

Hand specimen: Water worn, rounded beach cobble, with grey patina. Many bivalve fragments.

524-212 Calcreted limestone

Hand specimen: Fossiliferous limestone with powdery coating of calcrete. Solution runnels and Mn dendrites common.

524-216 Soil

Hand specimen: Poorly sorted soil from below calcrete ledge above Pliocene. Consists predominantly of calcrete grains, with well rounded quartz grains, foraminifera, seeds, gypsum and mollusc fragments. Very little clay present.

524-217 Calcreted Pliocene

Hand specimen: Same as 524-219.

524-223 Sandy limestone

Hand specimen: Very coarse sand sized, porous limestone with unidentifiable fossil fragments and quartz grains and granules. 100 cms above unconformity - Pliocene section.

524-224 Fossiliferous limestone

Hand specimen: Porous limestone with echinoids and mollusc internal and external moulds. No infilling of aragonite dissolved voids. Dominant macro-fossil is small 'cockle' ($\leqslant$ 3 cms). 170 cms above unconformity - Pliocene section.

524-226 Coral

Hand specimen: Scleractinian colonial coral - similar to *Plesiastrea* sp. Appears to be part of Pliocene, but may be Quaternary infilling of small depression, as it occurs at water level.

524-230 Fossiliferous limestone

Hand specimen: More compact, richly fossiliferous limestone, with many macro-fossil molluscs, still with primary shell. Material is being calcretized. Many Mn dendrites.

524-231 Calcrete 'clay'

Hand specimen: Clay taken from between calcrete laminae wrapped around large Pliocene boulder. Similar to 524-216, but lacking fossil fragments.

APPENDIX 10

PHOSPHATE IDENTIFICATION METHODS

(1) Staining. Attempted to stain with ammonium molybdate after pre-treatment with concentrated nitric acid. Did not obtain a yellow stain, but did not obtain a positive result with a piece of phosphorite either.

(2) Solution Testing. Chipped off some rock, weighed 1.0068 gms into beaker, digested with 10 mls conc. HNO_3 for about 15 minutes (heated to boiling). Initial effervescence left yellow-brown solution and largely colourless residue with a few dark particles. Final volume approx. 8 ml.

Test (a) : 5 ml above solution + 5 mls ammonium molybdate. Gave very pale yellow colour and finally a very small amount of yellow precipitate.

Test (b) : Phosphorite - small quantity dissolved in HNO_3. When treated as above - gave strong yellow colour. (This was not quantitative in that the rock sample was not weighed).

Test (c) : Solution made up from KH_2PO_4. 136.15 mg in 20 mls HNO_3 and H_2O to 50 mls. This contains 71 mg P_2O_5.

(i) 1.0 ml this solution + 5 ml ammonium molybdate gave strong yellow.

(ii) 0.1 ml this solution + 5 ml HNO_3 + 5 ml ammonium molybdate gave pale yellow colour. Settling to very small precipitate.

Very approximately, it may be that there is about the same amount of P_2O_5 in Test (a) as in (c)(ii), i.e. approx. 0.14 mg P_2O_5. Solution (a) came from more than 500 mg rock. Therefore it appears that the rock contains approximately 0.14 mg P_2O_5, i.e. less than 0.1% P_2O_5.

APPENDIX 11

ROCK SPECIMEN & THIN SECTION DESCRIPTIONS - QUATERNARY

524-300 Bryozoal limestone

Hand specimen : Porous, buff coloured bryozoal limestone, showing secondary crystallization of calcite. Rock appears to consist almost entirely of bryozoa, with minor mollusc fragments. Surface calcrete in part.

Thin section : Primary matrix is micrite, with secondary bladed and equant spar and neomorphic spar. 80% consists of micro-fossils and bryozoa (dominant). Variety of foraminifera, dominated by Miliolids. Echinoid fragments common. Ostracods rare.

524-301 Fossiliferous limestone with laminar calcrete.

Hand specimen : Laminar calcrete - 2.5 cm rim around core, consisting of many laminae of various colours. Interface between calcrete and core is rich in Mn dendrites and also has fine powdery calcrete. Fossiliferous core has rich Quaternary fauna.

Thin section : Calcrete consists of micritic laminar calcrete with indistinct boundaries. Minor voids healed with equant spar. No lithoskels discernible. Core material is richly fossiliferous, with minor well rounded quartz and feldspar grains. Foraminifera population dominated by Miliolids. Many mollusc fragments, with some showing dissolution, micritic envelopes. Matrix mainly micrite.

524-312 Ferruginised Material

Hand specimen : Similar to 524-431, but with some limonite areas.

Thin section : Very brecciated and variable sizes of grains. No grain to grain contacts. Carbonate grains have rounded inclusions of limonite. 50% limonite/haematite. 40% rhyo-dacite relict material. 10% carbonate.

524-314 Aeolianite

Hand specimen : Orange, calcareous aeolianite, cemented but easily crumbles between the fingers. Grain size $\leqslant$ 1 mm. Very porous and permeable.

Thin section : 70% lithoskels, of which 80% are calcareous algae - *Corallina cuvieri var. crispata*. Foraminifera fauna mainly *Discorbis* sp.

524-314 (cont'd) and *Elphidium* sp. Minor echinoid and bryozoa fragments. 50% of intergranular spaces are voids, 50% are filled with clay or spar. Foraminifera have equant spar infillings and micrite rims. 1% rounded quartz particles.

524-316 Calcreted rhyo-dacite

Hand specimen : Rhyo-dacite nuclei are very weathered to dark red ferruginised material. Each clast has laminar calcrete envelope. Massive calcrete is massive but granular.

Thin section : The rhyo-dacite shows individual grains enveloped by limonite. The rhyo-dacite nuclei are rimmed with micritic laminar calcrete. Within the massive micritic calcrete, voids and veinlets are infilled with later spar.

524-317 Rhyo-dacite and calcrete

Hand specimen : Weathered rhyo-dacite showing well-lineated mafics. Joint (approx. 1 cm wide) is infilled with calcrete. Sides of rhyo-dacite coated with laminar calcrete, with one side 1 mm thick whereas other side is 4 mms thick. Central area is infilled with nuclei surrounded by thin laminar rims supported by blocky calcrete.

Thin section : Rhyo-dacite is same as 524-410. Fine joints in rhyo-dacite are filled with calcrete. Laminar calcrete is micrite. Lithoclasts and lithoskels are coated with ferruginised laminae and supported by micritic calcrete, with spar veinlets.

524-321 Calcreted aeolianite

Hand specimen : Similar to 524-314, but with calcretization in some area giving more compact, less porous rock.

Thin section : Rock consists of 50% lithoskels, which are predominantly coralline algae, approx. 2% of which have a laminar calcrete envelope and are spar supported.

524-322 Calcrete

Hand specimen : White to cream coloured blocky calcrete with some dark grey nuclei. Soft and powdery.

Thin section : Lithoclasts and minor lithoskels as nuclei to pisolites, which are micrite supported. Some nuclei are coarse calcite, 10% are quartz clasts with embayed margins. Matrix forms 50% of rock.

524-324 Calcrete

Hand specimen : Pisolitic calcrete, with coalition of pisolites into sheet calcrete. Nuclei of pisolites are very small.

Thin section : Ooids and pisolites with many layered radial envelopes supported by buff-brown coloured micrite. Laminae boundaries are undulose and some nuclei polyclastic and cemented with carbonate. Occasional void is filled with calcite spar.

524-326 Calcreted aeolianite

Hand specimen : Similar to 524-321, but has been bleached and leached. Calcrete is white and powdery on surface.

Thin section : All clasts have brown laminar rims. The ooids are micrite matrix supported. Minor lithoskels.

524-327 Calcrete

Hand specimen : Thick (6 cms) slab of compact, yellow-brown laminar calcrete. Mn dendrites common.

Thin section : Minor lithoskels with indistinct boundaries. <1% embayed quartz clasts. Overall homogeneous micritic laminae with spar veinlets.

524-329 Calcrete

Hand specimen : Similar to lagoon-estuarine facies of Pliocene (524-214), but with orange laminar calcrete rim.

Thin section : Same as 524-214.

524-330 Sandy fossiliferous limestone

Hand specimen : Similar to 524-214, but fossils still clearly distinct and fragmented. Large algal blebs. Porous. Serpulids common. One face has thin veneer of calcrete.

Thin section : Large rounded quartz clasts. Foraminifera rich, large (0.2 cm) gastropod and bivalve fragments and algal fragments (0.5 cm) 50% of rock consists of lithoskels, many showing various calcitization stages.

524-332 Calcrete

Hand specimen : Specimen overlies 524-330 stratigraphically. Calcretization has destroyed most fossils. Porous.

Thin section : Lithoskels of *M. vertebralis*, other foraminifera, molluscs and algae and approx. 15% rounded and embayed quartz grains. No grain to grain contact. Clasts micrite supported, 524-332 (cont'd) with spar veinlets.

524-339 Calcrete

Hand specimen : Pisolites of calcrete coalesced to form block calcrete, which is coated ($\leqslant$ 1.5 cms) with laminar calcrete. Compact. Dense Mn dendrites common. Reddish colour.

Thin section : Massive micritic calcrete shows very embayed lithoskels (< 5%) and also equant spar infilling voids. Quartz clast boundaries are embayed and frayed. The micritic laminae have rare quartz clasts.

524-340 Calcrete

Hand specimen : Similar to 524-339, but no laminar calcrete except as pisolite rims. Appears to be newly coalesced.

Thin section : Similar to 524-339, but with more quartz clasts (8%).

524-302 Mud (below shellgrit)

Hand specimen : Miliolid rich, fine sand. Little clay material, mainly calcareous.

524-303 Mud (below *S. quinqueflora*)

Hand specimen : Similar to 524-302, but with many blue-green algae filaments.

524-304 Fossiliferous limestone

Hand specimen : Very poorly cemented limestone, with shells (fossils) still with macreous coating. *Phasianella* sp. and *Katelysia* sp. readily identifiable.

524-305 Calcreted fossiliferous limestone

Hand specimen : Ferruginised fossiliferous limestone, rich in gastropods of Recent types, with laminar calcrete coating.

524-306 Sand

Hand specimen : Predominantly calcareous sand. Fine grained, well sorted and partly wind frosted. Minor exotic clasts (<5%) but no quartz grains. Mollusc fragment, ostracods and coralline algae prevalent, minor calcareous sponge spicules. Foraminifera constitute about 40% of sand, with *Elphidium* sp. and *Discorbis* sp. dominant, but many other species present.

524-307 Sand

Hand specimen : 70-80% carbonate, 10% both rounded and angular quartz and 10% foreign clasts. Foraminifera assemblage similar to 524-306, with many showing signs of attrition.

524-308 Sand

Hand specimen : Carbonate rich, with <5% quartz grains (not rounded) and <5% foreign clasts. Predominantly mollusc fragments and foraminifera, showing signs of attrition. Foraminifera are dominated by *Elphidium* sp. and *Discorbis* sp. with no agglutinated species present. They are well sorted, probably due to winnowing. A few sponge spicules, ostracods and algal fragments are present.

524-309 Calcrete

Hand specimen : Angular calcreted clasts coalesced into sheet calcrete. Clasts are ferruginised.

524-310 Calcrete

Hand specimen : Similar to 524-309, but with larger clasts of rhyo-dacite cemented to-gether with friable white calcrete.

524-311 Laterite

Hand specimen : Ferruginised material with calcrete encrustation.

524-313 Aeolianite

Hand specimen : Light orange compact aeolianite with solution holes infilled with dark red fossil soil.

524-318 Serpulid Beach Rock

Hand specimen : Serpulid rich white beach rock, with minor molluscs, firmly cemented together.

524-319 Soil

Hand specimen : Fossil soil derived from aeolianite. Predominantly fine carbonate particles with limonite films. Minimal clay and quartz fractions. Some foraminifera and calcrete particles present.

524-320 Calcrete

Hand specimen : Light coloured blocky and laminar calcrete, similar to 524-324.

524-323 Soil

Hand specimen : Similar to 524-319, but finer and less limonite.

524-325 Calcrete

Hand specimen : Similar to 524-327, but with some small laminar rimmed pisolites within large laminar rimmed pisolites which have coalesced to give blocky calcrete.

524-328 Calcretized Fossiliferous Limestone

Hand specimen : Similar to 524-329, but with visible macro-fossils - mainly gastropods; and greater porosity.

524-331 Fossiliferous Limestone

Hand specimen : Porous, loosely consolidated fossiliferous limestone, with large *M. vertebralis* and *Cerithium* sp. Many quartz and rock fragment clasts.

524-334 Shellgrit

Hand specimen : Unsorted material, with approx. 30% quartz grains which are clear and show moderate rounding and sorting. Approx. 60% carbonate, predominantly shell fragments and sparse foraminifera. Attrition high. Minor organic material.

524-335 Mud

Hand specimen : Similar to 524-303, but with minor quartz, biotite and garnet grains. 10% foraminifera, with *Triloculina* sp. dominant. Ostracods common.

524-336 Sand

Hand specimen : Carbonate rich (>90%) with very few quartz grains. 75% of material consists of foraminifera with greatest variety seen, including textularians. A number of calcareous sponge spicules, coralline algae and seeds but few ostracods.

524-337 Sand

Hand specimen : Coarse material, containing high percentage of larger foraminifera, including many *M. vertebralis, Peneroplis* sp, *Discorbis* sp. and *Spiroloculina* sp. No quartz grains nor foreign clasts. Coralline algae, calcareous sponge spicules and serpuliids common, with minor ostracods and bryozoa.

524-338 *Posidonia australis*

Hand specimen : Few attached foraminifera - *Nubecularia* sp., with most attached biota being serpuliids and bryozoa.

524-341 Aeolianite

Hand specimen : Orange, easily crumbled aeolianite, with terrestrial gastropod specimen. Predominantly coralline algae.

524-342 'Clay'

Hand specimen : 'Clay' from within calcrete laminae around Pliocene boulder. Friable, orange coloured. Contains minor quartz grains.

APPENDIX 12 METHOD OF X-RAY DIFFRACTION

The sample was powdered and spread evenly as a slurry in ethanol on a glass plate, then allowed to dry. The mount was placed in the rotary sample holder of the Phillips 1010 X-ray diffractometer and analysed under the following conditions:-

Cobalt tube	-	Co $K\bar{\alpha}$
Filter	-	graphite goniometer
Scan speed	-	$\frac{1}{2}^{o}$/minute
Chart speed	-	5 mm/minute
Time constant	-	10
Slit widths	-	$2^{o}/\frac{1}{2}^{o}$
Range	-	100 cps
Kv/mA	-	30/30

A trace of the resulting peaks was obtained for the angles between 3^{o} and 70^{o}. The Bragg equation:

$$n\lambda = 2d \sin \Theta$$

was used to work out the interplanar spacings once 2Θ was measured from the peaks. The minerals present were determined from available tables.

APPENDIX 13

FORAMINIFERA TAXONOMY

Protista
Sarcodina

Order : Foraminifera (Eichwald), 1830

Suborder : Textulariina (Delage & Hérouard) 1896

Superfamily : Lituolacea (de Blainville) 1825

Family : Rzehakinidae (Cushman), 1933

Subfamily -

Miliammina fusca (Brady) 1870

Family : Ataxophragmidae (Schwager), 1877

Subfamily : Valvulininae (Berthelin), 1880

Clavulina difformis (Brady), 1924

Cribrobulimina polystoma (Parker & Jones) 1865

Suborder : Miliolina (Delage & Hérouard) 1896

Superfamily : Miliolacea (Ehrenberg), 1839

Family : Nubeculariidae (Jones), 1875

Subfamily : Nubeculariinae (Jones), 1875

Nubecularia lucifuga (Defrance), 1820

Subfamily : Spiroloculininae (Wiesner), 1920

Spiroloculina antillarum (d'Orbigny) 1839

Spiroloculina angusteoralis (Parr) 1950

Subfamily : Nodobaculariinae (Cushman) 1927

Vertebralina striata (d'Orbigny) 1826

Family : Miliolidae (Ehrenberg) 1839

Subfamily : Quinqueloculininae (Cushman) 1917

Quinqueloculina subpolygona

Quinqueloculina tenagos (≡*costata*) (d'Orbigny)

Triloculina oblonga (Montagu), 1932

Triloculina rotunda (d'Orbigny) 1826

Triloculina striatotrigonula (Parker & Jones) 1865

Triloculina tricarinata (d'Orbigny) 1826

Triloculina virgula (Pezzani) 1963

Subfamily : Miliolinellinae (Vella) 1957

Scutuloris sp.

Family : Soritidae (Ehrenberg) 1839

Subfamily : Peneroplinae (Schulze) 1854

Peneroplis-pertusus

Peneroplis planatus (Fichtel & Moll) 1826

Spirolina sp. (Lamarck) 1804

Subfamily : Soritinae (Ehrenberg) 1839

Marginopora vertebralis (Quoy & Gaimard) 1830

Suborder : Rotaliina (Delage & Hérouard), 1896

Superfamily : Nodosariacea (Ehrenberg) 1838

Family : Nodosariidae (Ehrenberg) 1838

Subfamily : Nodosariinae (Ehrenberg) 1838

Lagena bassensis

Lagena distoma-margaritifera (Parker & Jones) 1865

Subfamily : Plectofrondiculariinae (Cushman) 1927

Bolivinella folium (Parker & Jones) 1865

Family : Polymorphinidae (d'Orbigny) 1839

Subfamily : Polymorphininae (d'Orbigny) 1839

Polymorphina sp. (d'Orbigny) 1826

Family : Glandulinidae (Reuss) 1860

Subfamily : Oolininae (Loeblich & Tappan) 1961

Fissurina lucida (Williamson) 1848

Fissurina marginata (Montagu) 1803

Fissurina orbignyana (Sequenza) 1862

Superfamily : Buliminacea (Jones) 1875

Family : Bolivinitidae (Cushman) 1927

Bolivina sp. (d'Orbigny) 1839

Brizalina striatula (Cushman) 1922

Superfamily : Discorbacea (Ehrenberg) 1838

Family : Discorbidae (Ehrenberg) 1838

Subfamily : Discorbinae (Ehrenberg) 1838

Discorbis dimidiatus (Parker & Jones) 1862

Discorbis vesicularis var acervulinoides (Parr) 1932

Rosalina kennedyi

Family : Glabratellidae (Loeblich & Tappan)

Subfamily : -

Glabratella australensis (Heron, Allen & Earland) 1932

Superfamily : Spirillinacea (Ruess) 1862

Family : Spirillinidae (Ruess) 1862

Subfamily : Spirillininae (Ruess) 1862

Patellina corvugata (Williamson) 1858

Superfamily : Rotaliacea (Ehrenberg) 1839

Family : Rotaliidae (Ehrenberg) 1839

Subfamily : Rotaliinae (Ehrenberg) 1839

Ammonia beccari (Linné) 1758

Family : Elphidiidae (Galloway), 1933

Subfamily : Elphidiinae (Galloway) 1933

Elphidium articulatum (d'Orbigny) 1839

Elphidium crispum (Linné) 1758

Elphidium macellum (Fichtel & Moll) 1939

Elphidium pseudonodosum

Family : Planorbulinidae (Schwager) 1877

Subfamily -

Planorbulina mediterranensis (d'Orbigny), 1826

Superfamily : Cassidulinacea (d'Orbigny) 1839

Family : Annulopatellinidae (Loeblich & Tappan)

Subfamily : -

Annulopatellina annularis (Parker & Jones) 1860

Many specimens were identified by reference to the unpublished work of J. Cann.

PLATE 11

BIOCLASTS

a : Gastropod larva x 70.

b : *Serpulid* sp x 100

c : Unknown x 700

d : Calcareous sponge spicule x 70

e : Chenopod seed x 60

f : Bryozoa x 50

g : Coralline algae x 60

h : Coralline algae x 50

i : Coralline algae x 70

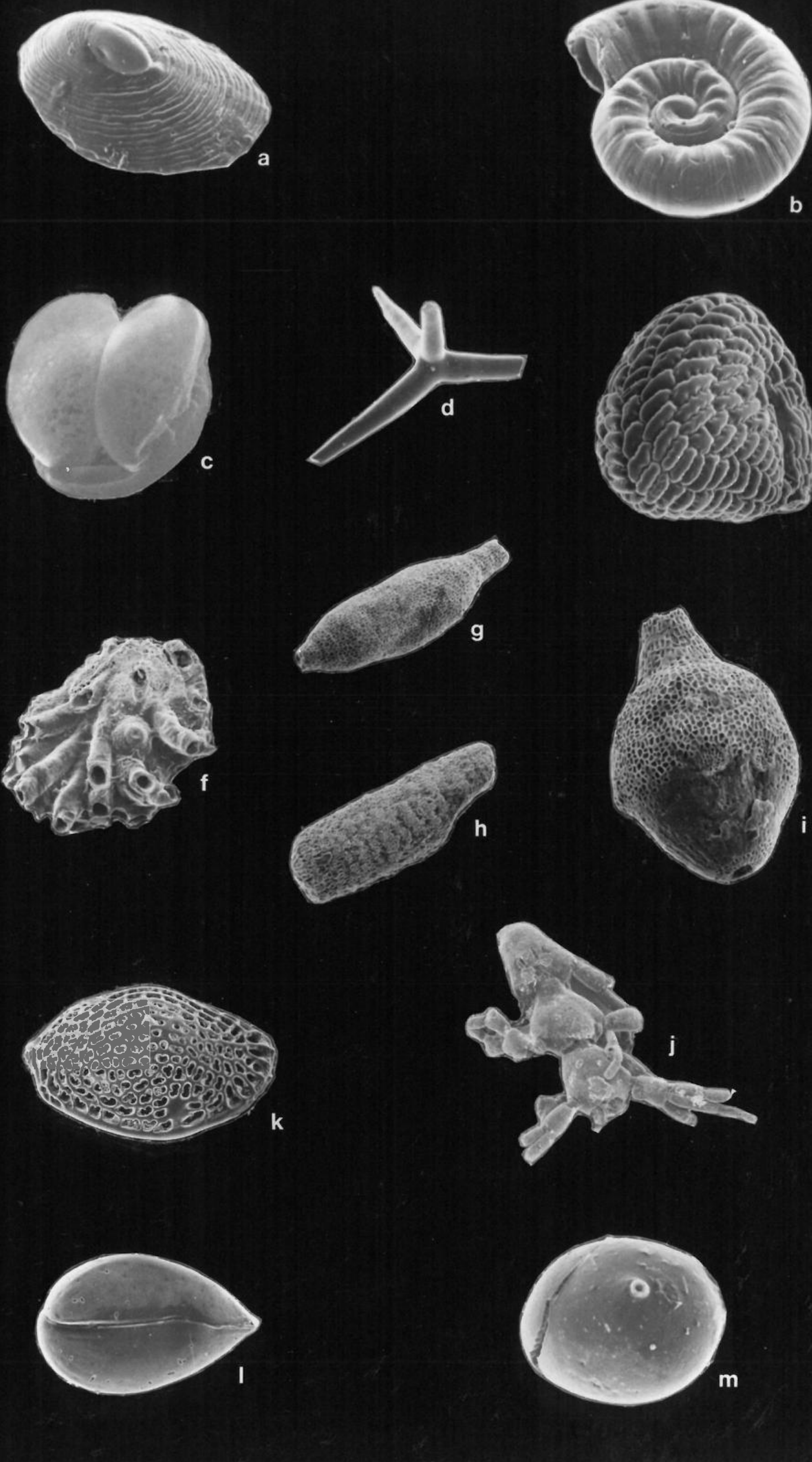
j : Coralline algae x 20

k : Ostracod x 60

l : Ostracod x 100

m : Unknown x 150.

PLATE 11



APPENDIX 14

Mg ANALYSIS

Mg content was determined using a Varian Atomic Absorption No. 6 under the following operating conditions:-

λ = 285.8 nm	P.M. = 275 V
I = 3 mA	height = 8
S.B.P = 0.20 nm	N_2O/acetylene oxidising flame.

The weighed foraminifera (or fragments) were dissolved in 10% HCl and made up to 100 mls with water. A blank was run as a control.

FRONTISPIECE

APPENDIX 16