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RECORD 1978/105

THE LATE CAINOZOIC SEDIMENTS OF SOUTHEASTERN SOUTH AUSTRALIA - LITHOLOGY AND MINERALOGY

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CONTENTS

ABSTRACT

Late Cainozoic sediments in southeastern South Australia are predominantly calcareous. They range from shallow marine calcareous quartz sands of Pliocene age and Pleistocene beach-dune deposits, which form a series of parallel ranges, to Pleistocene and Holocene lacustrine-estuarine calcilutites and dololutites, which occupy the inter-range areas. Carbonate content of the sediments commonly exceeds 50% by weight. Lithologically and mineralogically, the sediments vary in response to range of depositional environments, changes in nature and amount of terrigenous and biogenic input, carbonate precipitation in the inter-range areas, and the effects of diagenesis. The beach-dune deposits show increasing diagenesis inland, corresponding to the replacement of aragonite by calcite and the loss of small amounts of magnesium from the calcite. The dololutites in the inter-range areas are typically protodolomites and similar to the dolomites in the modern Coorong lagoon system and inland lakes of the Naracoorte area.

INTRODUCTION

The extensive and largely regressive sequence of late Cainozoic sediments in southeastern South Australia (Fig. 1) has been a subject of considerable interest to workers over several decades. Descriptions of the sediments date back to Clarke (1896) and Tate (1898), and include Crocker & Cotton (1946), Tindale (1947, 1959), Hossfeld (1950), Sprigg (1952a, 1952b, 1959), Blackburn (1966a, 1966b), and Firman (1967, 1969, 1973). Much of the interest lies in the possible relevance of the sequence to determinations of Pleistocene sea-level changes. In 1974 and 1975, the Bureau of Mineral Resources, the Geological Survey of the South Australian Department of Mines, and the Department of Marine Geology, Flinders University undertook a detailed study of the sequence between Robe and Naracoorte, and west of Bordertown. This work was undertaken to provide, by a program of systematic drilling, detailed stratigraphic and other information, and samples for possible radiometric dating. Initial results of this work, including brief descriptions of the sediments, were presented by Cook & others (1977). Results of a heavy-mineral study of the sediments were given by Colwell (1976, 1979).

The purpose of this paper is to describe in detail the lithology and mineralogy of the sediments intersected in the drilling program.

GENERAL NATURE OF THE SEQUENCE

As noted by early workers in the region, southeastern South Australia is dominated by a succession of beach-dune shoreline accumulations (Figs. 1 & 2). These have been stranded on a coastal plain undergoing gentle regional uplift associated with a broad northeast-trending culmination (the Gambier Upwarp), which extends through the southern part of the region (Sprigg, 1952a). The beach-dune deposits (Bridgewater Formation of Boutakoff, 1963) consist for the most part of calcareous sands and quartzose calcarenites, composed of skeletal carbonate, quartz, minor feldspar, and trace amounts of heavy minerals. They form a series of parallel ranges separated by flats underlain by lacustrine, lagoonal, paludal, and estuarine deposits - mainly marls and clays with a small proportion of fine-grained calcareous sands. A Pliocene calcareous quartz sand unit (of probable shallow marine origin),

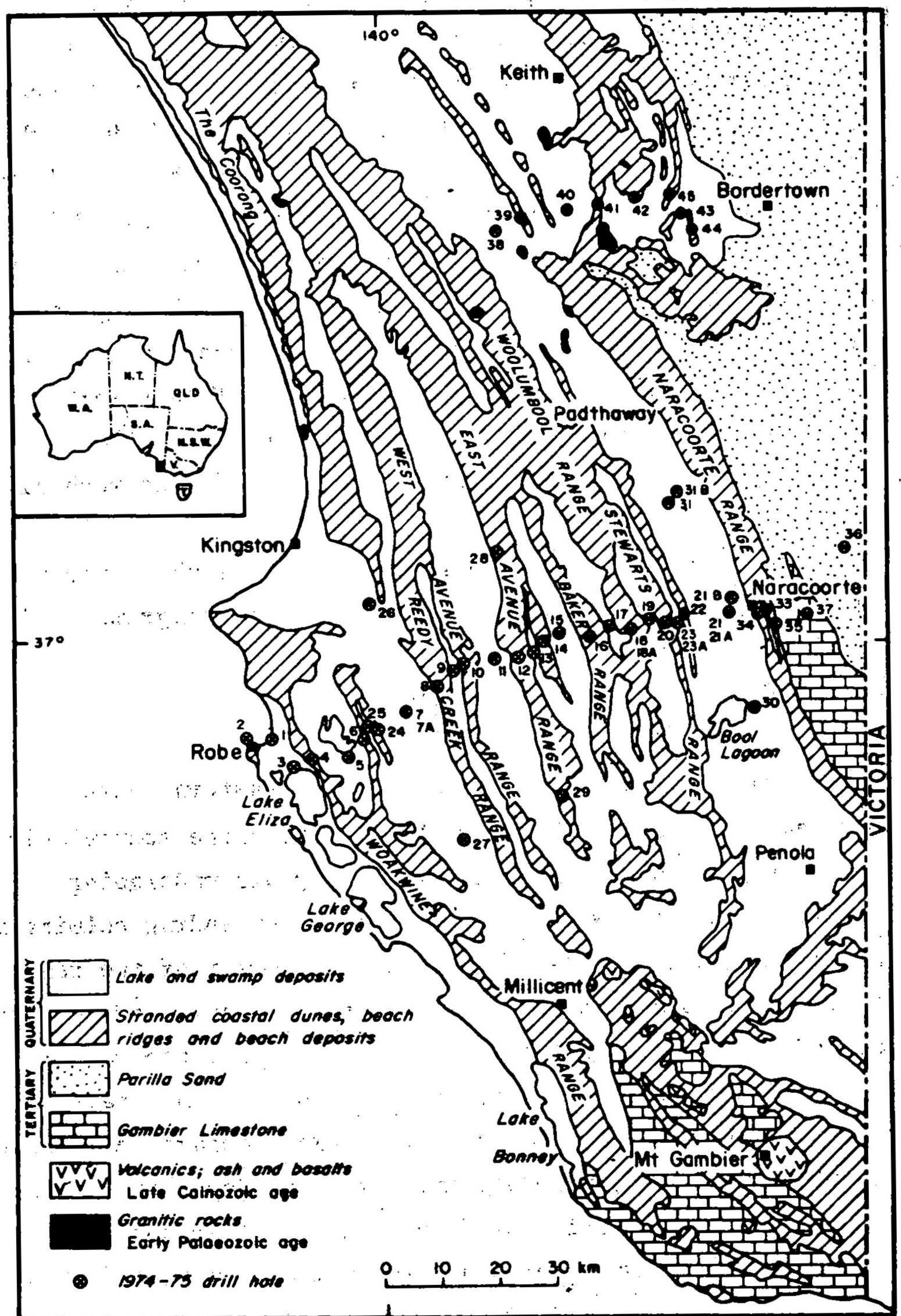

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Fig. 1 The geology of southeastern South Australia and the location of holes drilled during the 1974-75 program (from Cook & others, 1977).

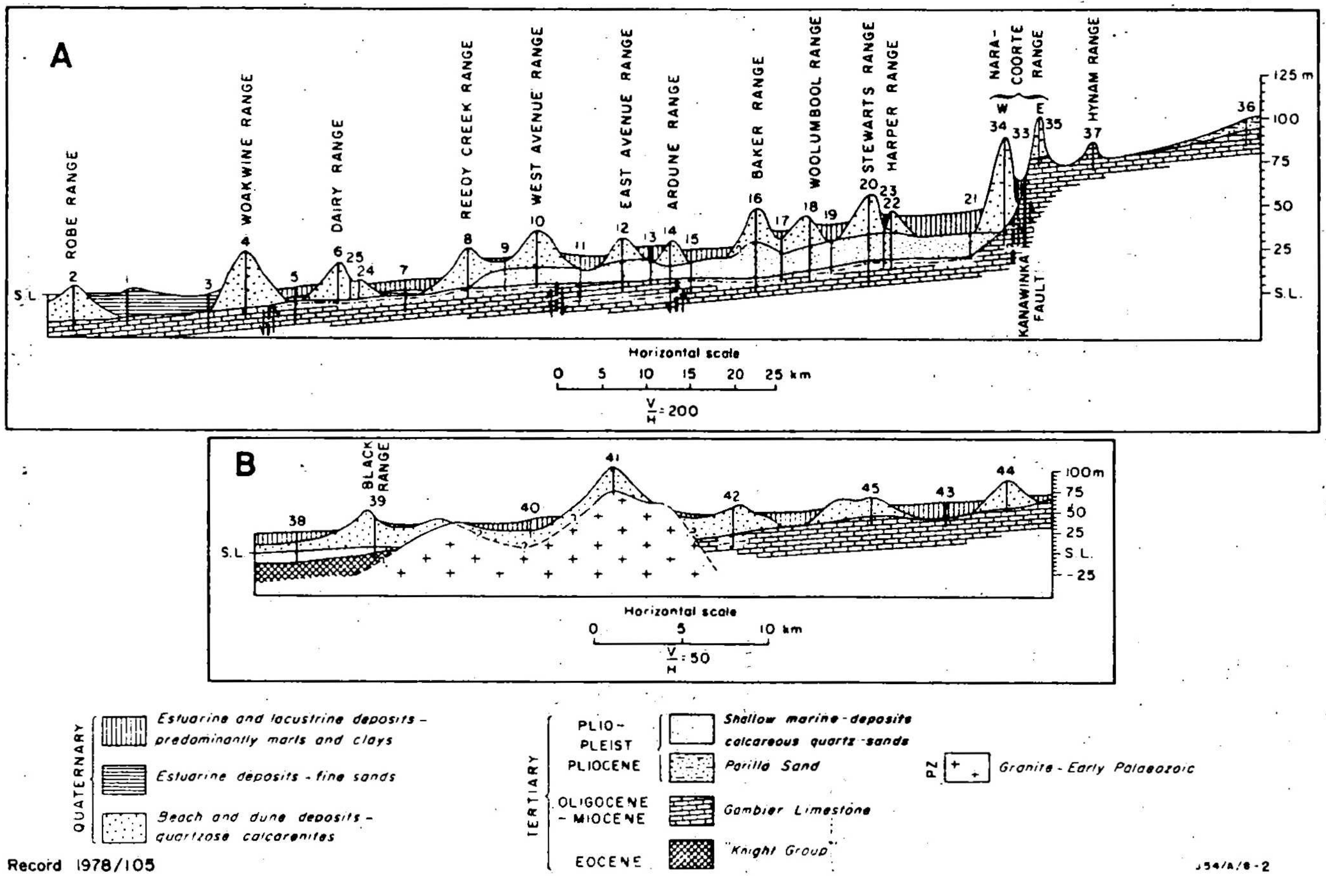

Fig.2 Sections through the late Cainozoic sequence in (A) the Robe—Naracoorte and (B) Bordertown areas (from Cook & others, 1977).

which does not crop out, underlies the beach, dune, and interdune deposits throughout much of the region (Cook & others, 1977), and the entire sequence is underlain by Oligocene-Miocene Gambier Limestone. The latter is disrupted by a major fault system, the Kanawinka Fault, along the region's eastern margin. Late Cainozoic quartzose sediments of the Murray Basin (Parilla Sand) extend into the region in the east and northeast. In the Bordertown area, beach-dune deposits overlie Lower Palaeozoic granites, Gambier Limestone, and Pliocene calcareous sands.

Overall, the late Cainozoic sequence is dominated by calcareous sands, calcarenites, calcilutites and dololutites. This appears to reflect (i) a broad offshore zone of active biological production of carbonate, particularly shell material, (ii) a relatively low terrigenous input, and (iii) precipitation of carbonates from groundwaters in the inter-range areas.

METHODS USED IN THIS STUDY

Texture and fabric

The sediments were initially described and logged in the field (the Robe-Naracoorte drill holes by P.J. Cook and D.A. Schwebel, and the Bordertown holes by J.B. Colwell). Subsequent textural and fabric studies were made in the laboratory using thin sections. Unconsolidated sands were examined under a binocular microscope.

Mineralogy

Qualitative identification and quantitative determinations were carried out using standard XRD methods. Mole % $MgCO_3$ was determined for Mg calcite and dolomite by the peak shift method of Goldsmith & Graf (1958a, 1958b).

Geochemistry

Atomic absorption spectrophotometry was used to determine the magnesium, strontium, zinc, iron, manganese, nickel, copper and lead contents of the acetic acid-soluble fraction of 375 samples. A molybdenum blue spectrophotometric method was used to determine P_2O_5.

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DESCRIPTION OF THE SEDIMENTS

Pliocene shallow marine sands (Cook & others, 1977)

These sands, which were largely delineated in the 1974 and 1975 drilling, extend through the eastern part of the region. In the Robe-Naracoorte area they disconformably overlie bryozoan sediments of the Gambier Limestone; further to the north they overlie Knight Group sediments on the Padthaway Ridge. Lithologically the sands range from quartzose calcarenites to calcareous quartz sands. Carbonate values generally range between 40 and 70 percent by weight (Fig. 3), although values as low as 10 percent occur in the eastern part of the region, apparently reflecting an increased terrigenous input from the east. The sediments consist for the most part of a fine-grained mixture of moderately-sorted, angular or subangular biogenic carbonate and quartz, with traces of feldspar, mica (biotite and muscovite), heavy minerals, and in places, glauconite (occurring both as rounded grains and as infillings in foraminifera tests). The biogenic carbonate typically consists of bivalve fragments, Bryozoa, foraminifera, coralline algae and echinoid fragments (Figs. 4 & 5). Sponge spicules and other components are present in trace amounts. Calcareous lithoclasts occur in places. The benthonic and planktonic foraminifera yield an early Pliocene age, and this suggests, as noted by Cook & others (1977), possible correlation of the unit with the early Pliocene Loxton Sands of Ludbrook (1961).

Mineralogically the carbonate fraction consists of low-Mg calcite with or without aragonite (Fig. 6); high aragonite values corresponding with relatively high contents of molluscan shell material which occur towards the base of the unit in some areas. Traces of dolomite are found in a small proportion of the sediments. Despite their retention of internal textural details, high-Mg calcite components such as coralline algae and echinoids appear from XRD traces to have lost the major part of their magnesium and are now low-Mg calcite. Many original aragonite components have been replaced by calcite.

Although most of the sediments are unconsolidated, thin well-cemented bands occur in places, mainly towards the base of the unit. These typically contain a fine-grained calcite cement (see Fig. 5).

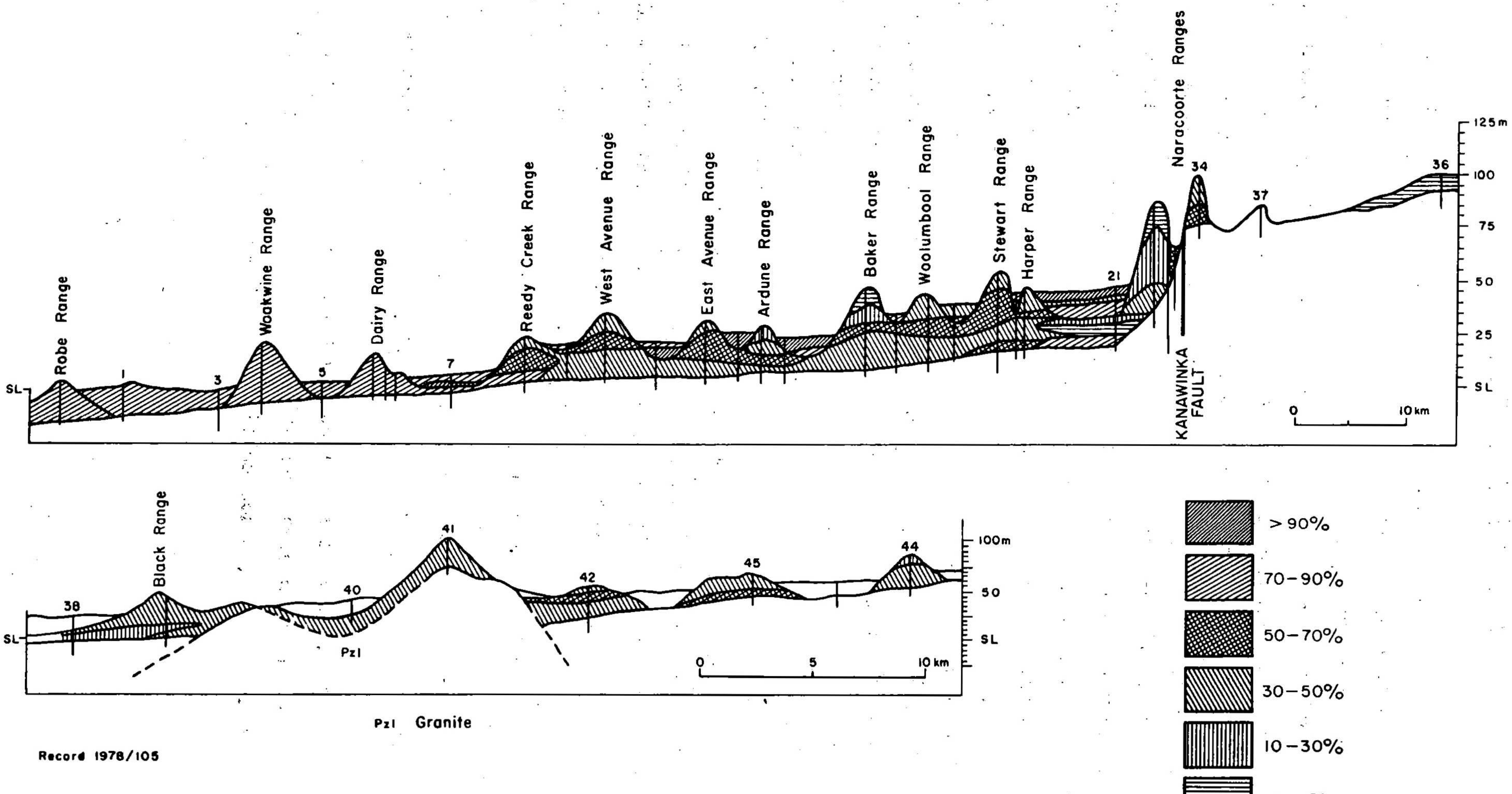

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Fig. 3 Carbonate content (% by weight) of sediments.

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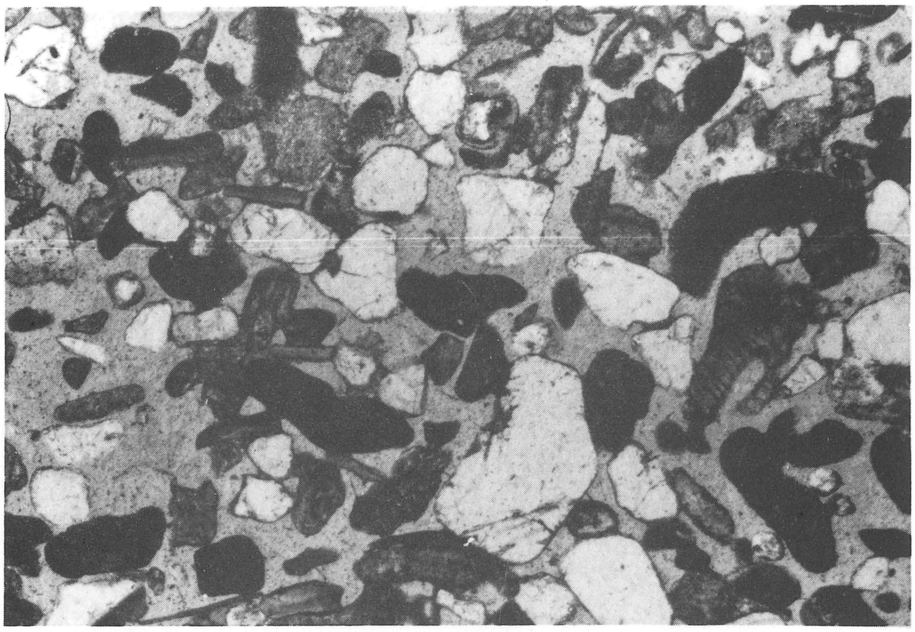

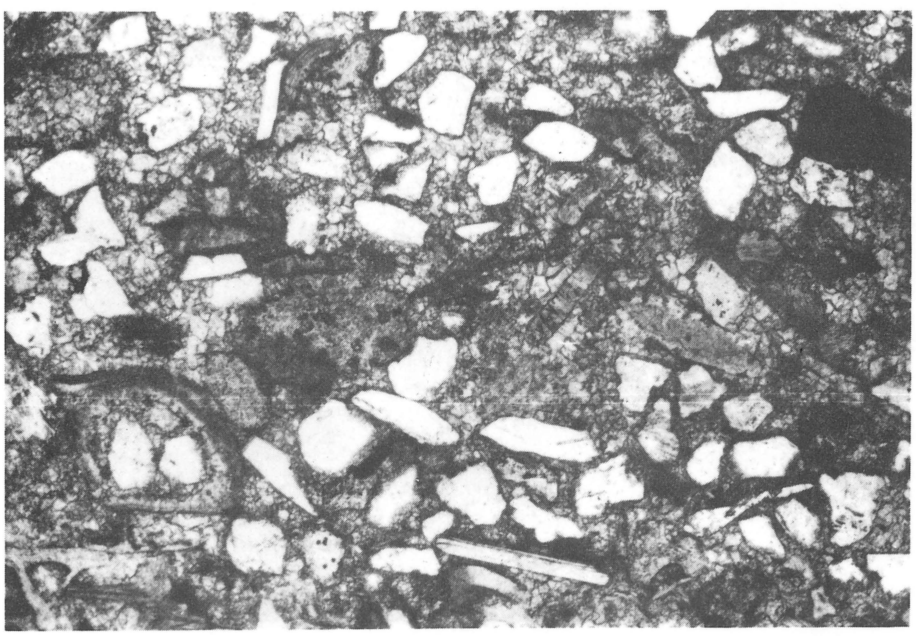

Fig. 4. Photomicrograph of unconsolidated Pliocene calcareous quartz sand. x36 (Neg. No. M/2275).

Fig. 5. Photomicrograph of a well-cemented band within the Pliocene calcareous quartz sand. x93 (Neg. No. M/2275).

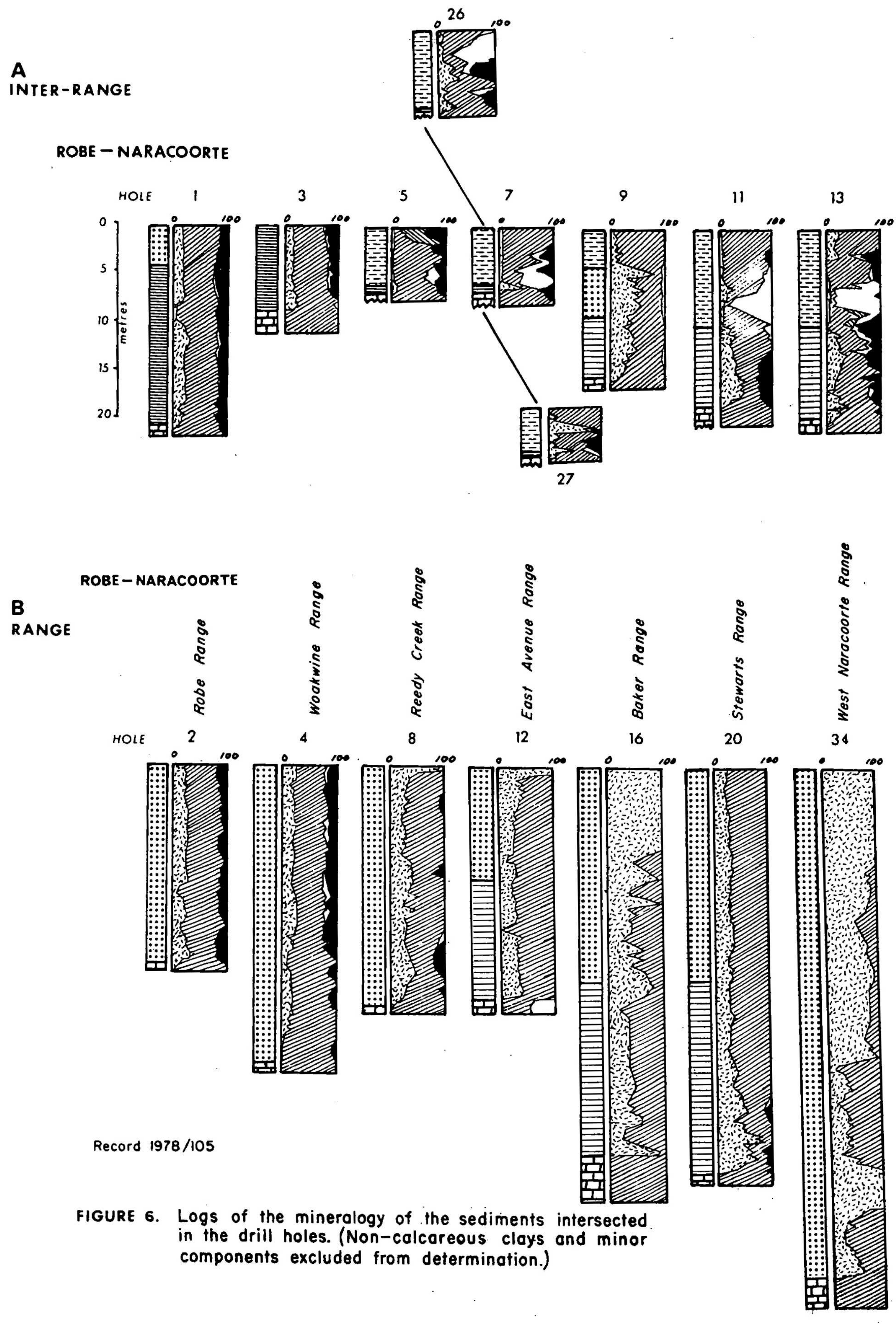

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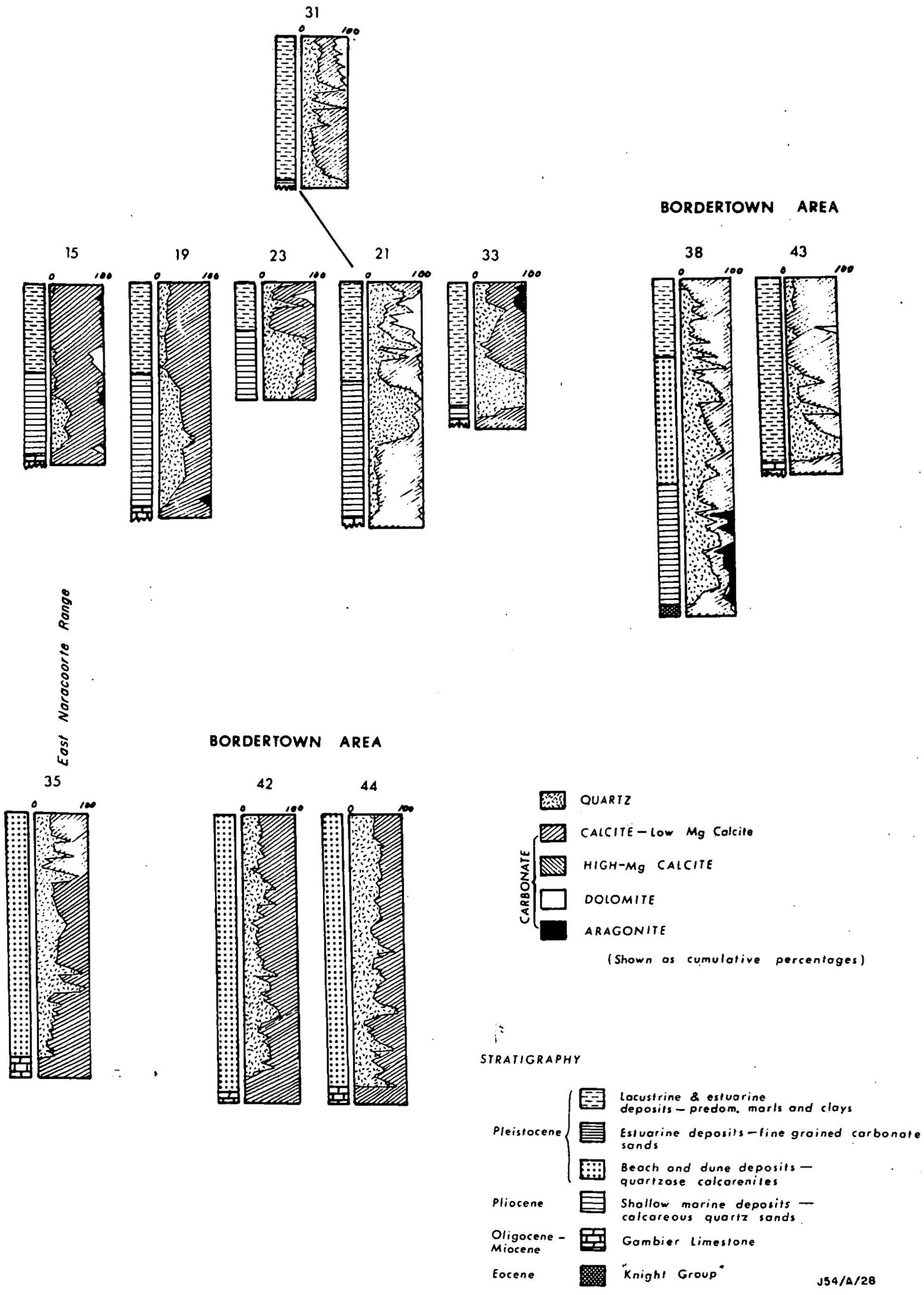
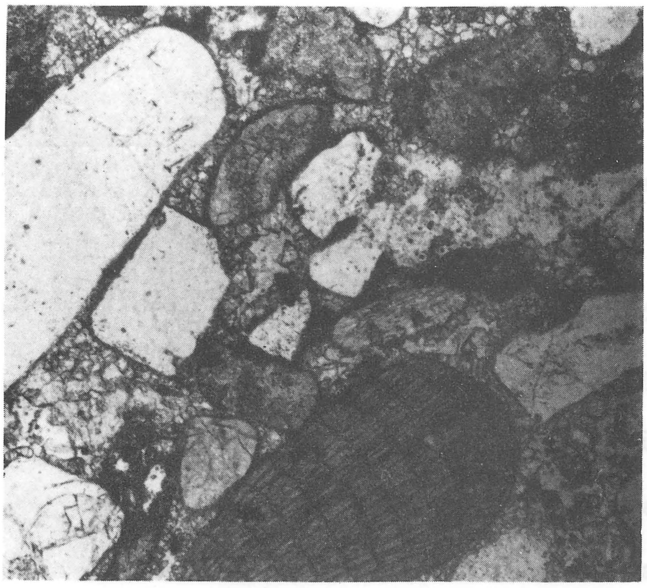
FIGURE 6. Logs of the mineralogy of the sediments intersected in the drill holes. (Non-calcareous clays and minor components excluded from determination.)

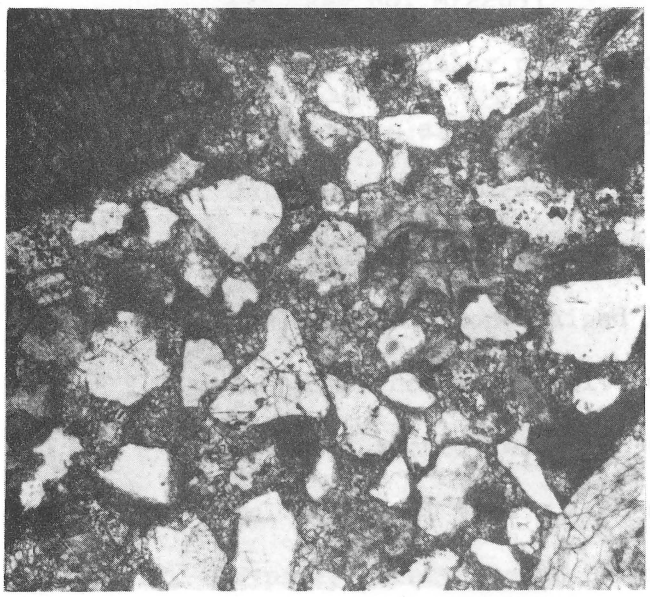

31
15
19
23
21
33
BORDERTOWN AREA
38
43
0
100
East Naracoorte Range
BORDERTOWN AREA
35
42
44
QUARTZ
CARBONATE
CALCITE – Low Mg Calcite
HIGH-Mg CALCITE
DOLOMITE
ARAGONITE
(Shown as cumulative percentages)
STRATIGRAPHY
Pleistocene
Lacustrine & estuarine deposits – predom. marls and clays
Estuarine deposits – fine grained carbonate sands
Beach and dune deposits – quartzose calcarenites
Pliocene
Shallow marine deposits – calcareous quartz sands
Oligocene – Miocene
Gambier Limestone
Eocene
"Knight Group"
J54/A/28

A



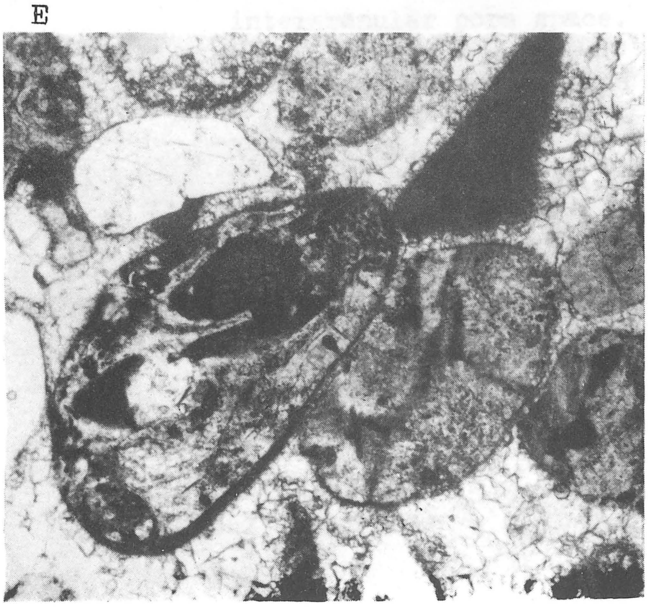
B

C



D

E



F

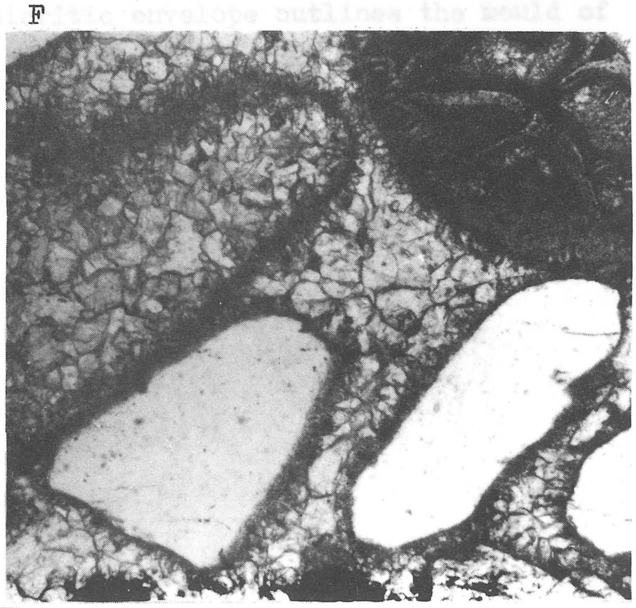


FIGURE : 7 A-F Photomicrographs of skeletal and other components of the beach-dune deposits.

Pleistocene beach-dune deposits

These sediments, which form the prominent ranges of the region, form part of the Bridgewater Formation, a unit defined in Victoria by Boutakoff (1963) as calcareous dunes and dune limestones. The formation is subdivided in parts of southeastern South Australia into an upper and a lower member separated by the Ripon Calcrete (Firman, 1969). Although the precise age of the deposits remains unknown, palaeomagnetic evidence suggests that the sequence to the west of East Naracoorte Range is less than 690 000 years old (Cook & others, 1977). In general terms the sequence appears to young towards the present coastline.

The sediments consist for the most part of quartzose calcarenites, composed of strongly abraded skeletal carbonate, quartz, minor feldspar, and trace amounts of heavy minerals. The skeletal material typically consists of bivalve debris (the dominant component), coralline algae (common), Bryozoa (common), whole and fragmented foraminifera (trace to common), and echinoid plates, spines, and other components (trace to common) (Fig. 7, A-F). There is some evidence, as noted by Cook and co-workers, of a downward increase in shelf-derived skeletal material. This is particularly noticeable in an increase in the proportion of bryozoan material, some of which is probably derived via reworking from the Gambier Limestone. Much of the carbonate fraction, particularly in the upper part of the formation, is stained or partly replaced by iron oxides, imparting a yellowish orange to light brown colour to the sediment. Calcrete commonly veneers the sediments.

Clasts are relatively common in the sediments and range from older indurated and commonly iron-stained calcarenite to bryozoan limestone. Examples are shown in Figure 7, D and E.

The carbonate content of the deposits decreases inland. In the Robe, Woakwine, and Dairy Ranges, carbonate abundance is generally between 70 and 90 percent. Farther inland, values decrease significantly and become more variable, commonly falling below 50 percent (Fig. 3). This decrease probably reflects, in addition to the increasing age of the deposits inland, a significant contribution of terrigenous detritus to the more inland deposits from quartzose Pliocene sands eroded at the western end of the section, a view supported by the heavy-mineral studies of Colwell (1976, 1979).

Several of the inland ranges display an increase in carbonate content with depth. This feature is most marked in the Baker and West Naracoorte Ranges, where carbonate values range from less than 10 percent (slightly clayey quartz sands) in the upper part to 50 percent towards the base. This depletion of carbonate in the upper part is probably the result of leaching of the carbonate, partly associated in the case of the West Naracoorte Range with the development of a number of soil horizons. These horizons clearly indicate the composite nature of the range which, divides into four separate ridges north of Padthaway.

Mineralogically, the sediments constituting the ranges show a progressive elimination of unstable and metastable carbonate components with increasing age (distance inland). Aragonite is progressively eliminated and is absent from the deposits to the east of the Reedy Creek Range (Fig. 6, B). Original high-Mg calcite components such as coralline algae and echinoids have lost the major part of their magnesium and are now low-Mg calcite. Traces of dolomite occur in a few of the sediments and appear to represent formation <u>in situ</u> during early stages of diagenesis (Schwebel, 1977). The dolomite typically occurs as well-formed rhombs.

The results of geochemical measurements made on the acetic acid-soluble fraction of the sediments (Figs. 8-10) reflect the progressive diagenesis of the deposits inland. Magnesium and strontium decrease dramatically between the woakwine and Reedy Creek Ranges, correlating with the elimination of aragonite from the system (transformation of aragonite to calcite) and the partial removal of small amounts of magnesium from the calcite. Farther inland, values show a steady but less dramatic decrease to the Baker Range, and thereafter remain relatively constant; phosphate values show a similar trend (Fig. 10). Iron and manganese values (not shown) remain relatively constant at approximately 150-250 and 50-100 ppm respectively, becoming slightly higher in some of the more inland deposits, presumably associated with secondary mobilization. Zinc, nickel, copper, and lead values generally remain below the detection limits of the atomic absorption unit.

The beach-dune deposits have undergone cementation in both the vadose and phreatic zones. As noted by Schwebel (1977), pores in the vadose zone are commonly lined with meniscus cements of sparry calcite; those in the phreatic zone are commonly filled. Typical examples are shown in Figure 7. In both zones, cemented framework components are commonly enclosed by a thin envelope of micrite. In the case of the phreatic zone, this enve-

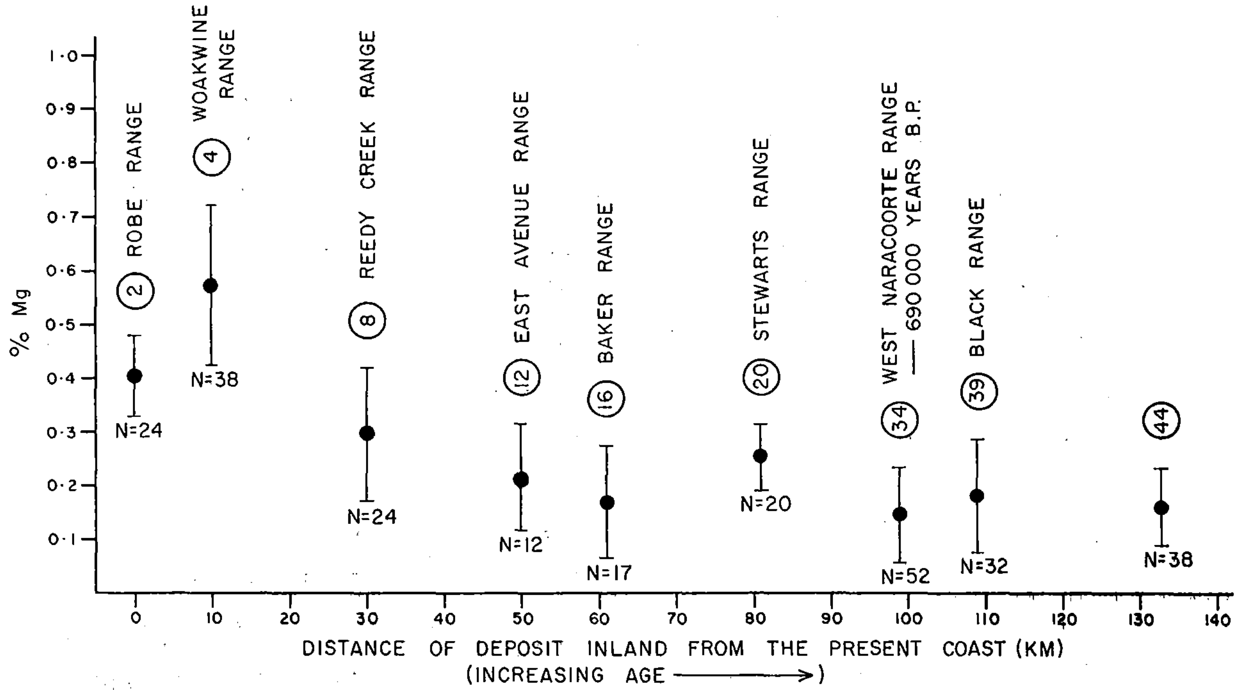
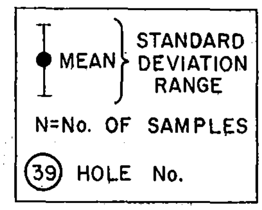


Fig. 8 Plot of magnesium content against distance of the deposit inland from the present coast (≈age)



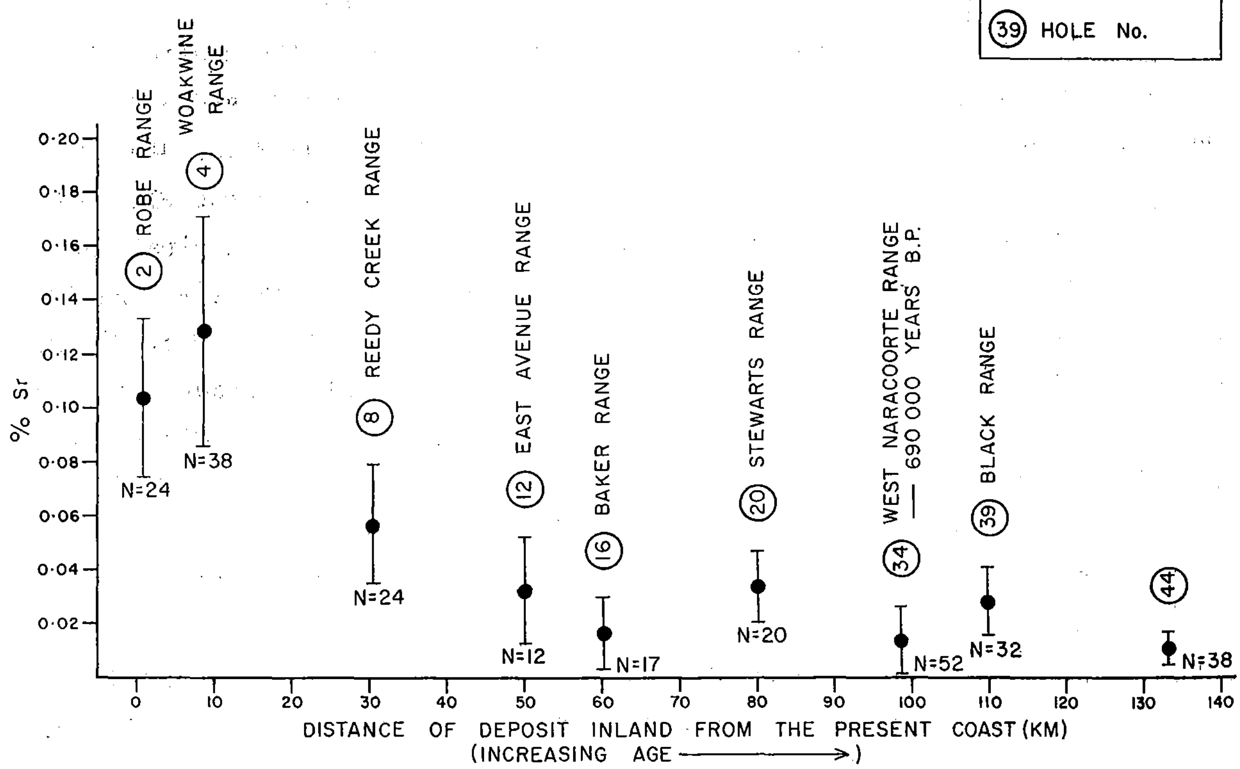


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Fig. 9 Plot of strontium content against distance of the deposit inland from the present coast (≈age)

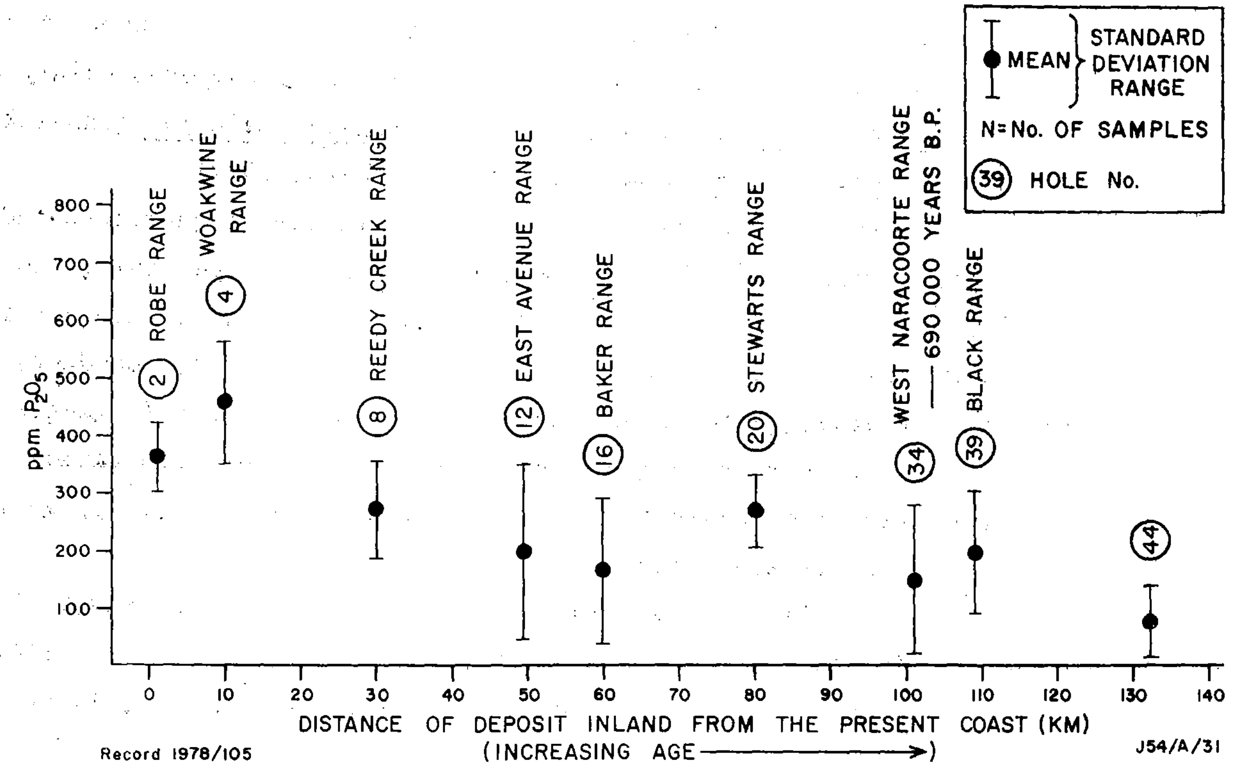

Fig. 10 Plot of P_2O_5 content against distance of the deposit inland from the present coast (≈ age)

lope commonly outlines the moulds of skeletal fragments (mainly mollusc fragments) which have now been filled with sparry calcite (Fig. 7F); examples of this occur in each range and become increasingly abundant in the more inland (older) deposits.

Pleistocene estuarine sands

As noted by Cook & others (1977), light grey sands of probable estuarine origin occupy the area between the Robe and Woakwine Ranges, as well as occurring at the base of several inland inter-range sequences (Fig. 2). Similar sequences (the Anadara Beds of Sprigg, 1952; Glanville Formation of Firman, 1973) (not distinguished on Figure 2) occur between the Woakwine and Reedy Creek Ranges, where they contain beds composed mainly of the bivalves *Anadara trapezia* (Deshayes) and *Katelysia scalarina* (Lamarck), as well as some *Ostrea sinuta* (Lamarck) (Cook & others, 1977).

Lithologically, the sands consist of a mixture of quartzose and almost pure calcarenites; carbonate contents typically range from 70 to 90 percent by weight. The carbonate fraction is generally moderately sorted and fine to medium-grained, and consists of mollusc fragments (abundant), formaminifera, Bryozoa, gasteropods, sponge spicules, echinoid fragments and coralline algae. Few of the sediments show any sign of cementation. The terrigenous fraction consists of fine to coarse-grained quartz, minor feldspar and traces of heavy minerals.

Mineralogically, the sediments consist of a mixture of 50 to 60 percent low-Mg calcite, 20 to 23 percent aragonite (mainly shell material), 15 to 25 percent quartz, and 1 to 5 percent dolomite (well-crystallised rhombs).

Pleistocene and Holocene estuarine-lagoonal and lacustrine deposits

These deposits occupy the major part of the inter-range areas. Where drilled, they range in thickness from less than 4 m (hole 9) to a maximum of 13 m (hole 21, on the inter-range flats immediately west of Naracoorte), and consist predominantly of pale grey and white calcareous muds, commonly underlain by a thin sequence of green to olive-grey poorly calcareous muds of bay or estuarine origin. Thin layers of calcrete and beds of fine-grained quartz carbonate sand occur in places.

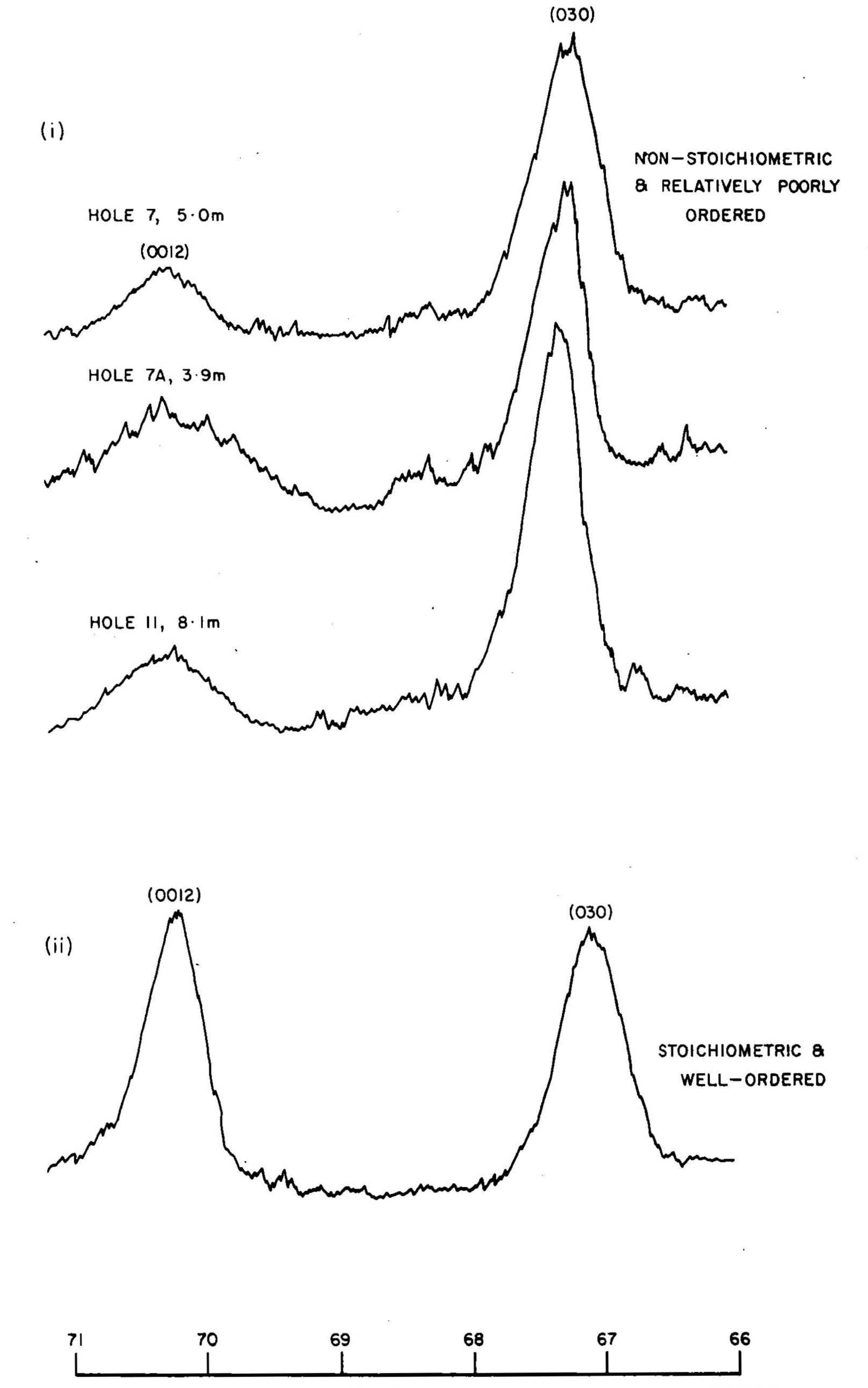

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Fig. 11 XRD traces showing dolomite ordering peaks. (i) Southeast South Australian dolomites, (ii) standard (stoichiometric) dolomite after Supko (1977). Degree of ordering is indicated by the relative height of the peak at 70·54° 2θ to that at 67·42° 2θ. Dolomites in (i) contain 5 to 6 mole % excess $CaCO_3$.

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Mineralogically, the carbonate fraction of the sediments consists predominantly of low-Mg calcite (Fig. 6). High-Mg calcite occurs only in the upper part of hole 5 (Fig. 6), where it is associated with recent deposits of skeletal debris built up on the southern shore of Lake Hawdon North. Aragonite, which occurs in both marls and skeletal components (mainly Coxiella shells), is common in places, and comprises up to 40 percent of the carbonate fraction. Dolomite occurs as a major component in several areas (see Fig. 6), where it typically displays the characteristics of a non-ideal, calcian-rich or protodolomite as defined by Goldsmith & Graf (1958b), Graf & Goldsmith (1956), and Gaines (1977). It has an enlarged unit cell consistent with an excess of approximately 5 mole % $CaCO_3$ over the ideal $CaCO_3$: $MgCO_3$ ratio. Ordering reflections, although present, are typically weakly developed (Fig. 11). In general, these characteristics are the same as those of dolomites occurring in the modern environments of the Coorong lagoon system (Skinner, 1963) and the inland lakes of the Naracoorte area (Lake Omerod etc; von der Borch, 1976).

In general, the mineral sequence lacks the systematic variation in composition shown to be associated with the modern analogue of the inland inter-range areas, the modern Coorong system (Skinner, 1963; von der Borch, 1976; von der Borch & others, 1975). In its ideal form, the Coorong sequence passes upward from a basal marine or lagoonal unit of calcite and aragonite, through a protodolomite and Mg calcite lacustrine unit, to culminate in an uppermost dolomite or dolomite and magnesite unit (von der Borch, 1976). In both the Coorong and in the inland inter-range areas, carbonate precipitation appears to be controlled by a complex mixture of hydrological and other factors, many of which remain to be identified.

Most of the deposits are beyond the range of radiocarbon dating, although several ages have been obtained on upper parts of the sequence (Table 1). These indicate an average rate of deposition of approximately 0.13 mm yr^{-1} for the sediments between 2.3 and 2.9 m in hole 21, and a rate of less than 0.32 mm yr^{-1} for the sediments between 0.4 and 5.0 m in hole 7. The actual rates probably varied fairly widely in response to changing hydrological conditions.

TABLE 1. RADIOCARBON AGES

Sample No.	Hole	Depth (m)	Lab. No.	Age	Remarks
74638002	21A	2.3	NSW 122	22,000 ± 600*	Calcilutite
74638004	21A	2.9	NSW 123	26,600 ± 800*	Calcilutite
76639001	7	0.4	NSW 176	15,700 ± 210	Calcilutite
76639002	7	5.0	NSW 177	> 30,000	Calcilutite
76639003	15	3.9	NSW 178	> 30,000	Partly cemented calcilutite
76639004	15	5.0	NSW 179	> 30,000	Calcilutite
76639005	33	0.6	NSW 180	> 29,000	Slightly sandy calcilutite
76639006	38	1.2	NSW 181	> 30,000	Calcilutite
76639007	43	0.6	NSW 182	> 28,000	Calcilutite partly calcrete
76639008	43	4.6	NSW 183	> 28,000	Calcilutite

* Previously published by Cook & others (1977)

SUMMARY AND CONCLUSIONS

The late Cainozoic sediments of southeastern South Australia are predominantly calcareous, ranging from shallow marine calcareous quartz sands of Pliocene age and Pleistocene beach-dune deposits, which form a series of parallel ranges, to Pleistocene and Holocene lacustrine-estuarine calcilutites and dololutites, which occupy the inter-range areas. Their calcareous nature apparently reflects a broad offshore zone of active biological production of carbonate, a relatively low terrigenous input, and carbonate precipitation from groundwaters in the inter-range areas. Carbonate content of the sediments commonly exceeds 50% by weight. Lithologically and mineralogically, the sediments vary in response to changes in the ratio of terrigenous to biogenic detritus, the nature of the biogenic carbonate, the nature of carbonate groundwater precipitates, and the effects of diagenesis, which, in the case of the beach-dune ranges, has tended to remove unstable and metastable minerals from the carbonate fraction. The increased diagenesis of the older beach-dune deposits inland is reflected in a significant decrease in Mg, Sr and P_2O_5 contents of the acetic acid-soluble fraction of the sediments between the Woakwine and Baker Ranges. This decrease corresponds to the replacement of aragonite by calcite, and the loss of small amounts of magnesium from the calcite. In general, the beach-dune deposits to the west of the Reedy Creek Range consist predominantly of low-Mg calcite, quartz, and aragonite; those to the east consist mainly of low-Mg calcite and quartz.

The sediments in the inter-range areas contain thick sequences of carbonates ranging from calcilutites to dololutites. The dololutites are typically protodolomites with weakly developed ordering reflections and an excess of approximately 5 mole % $CaCO_3$ over the ideal $CaCO_3$:$MgCO_3$ ratio. These are similar to the dolomites in the modern Coorang lagoon system and inland lakes of the Naracoorte area.

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