



SEDIMENTATION IN THE COORONG LAGOON.
SOUTH AUSTRALIA.

by

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SUMMARY.

The Coorong is a flat, low-lying area, separated from the Southern Ocean by a range of Recent sand dunes and bordered along its landward margin by a composite range of Pleistocene dunes. This interdunal depression is occupied by mud-flats, numerous ephemeral lakes and a long lagoon, the Coorong Lagoon. At the present time calcium and magnesium carbonates are being deposited in parts of the Coorong. Several assemblages of these minerals have been described in the course of the previous investigations summarized by Skinner (1963), Alderman (in press) and von der Borch (1962 and in press). These investigations were mainly concerned with the lakes and the southern-most part of the lagoon. The present investigation has been directed at ascertaining the nature of the sedimentation proceeding within the lagoon, which extends north-westwards beyond the previously described areas.

The Coorong Lagoon is a coastal lagoon occupying the northern-most two-thirds of the Coorong. The deep-water section of the lagoon is divided into a number of basin- and trough-shaped depressions, most of which are interconnected by passages of deep water. The lagoon is divided into two major divisions, the Northern Lagoon and the Southern Lagoon. These are joined by a narrow channel, which is very shallow in places.

The waters of the lagoon are derived from two principal sources, the River Murray and the Southern Ocean. Water

from both these sources enters the lagoon at its northern end and the lagoon is completely separated from the ocean except for a single connection through the mouth of the river. At the present time no other streams run into the lagoon. There is a marked seasonal oscillation of both water level and water compositions and during the period of low water level the Northern and Southern Lagoon are virtually separated from each other. The Northern Lagoon shows alternating periods of brackish and hypersaline conditions, while the Southern Lagoon, which is more isolated from the effects of the River Murray, is permanently hypersaline. The dissolved salts in the lagoon water have been derived mainly from the ocean, so that the waters of the Southern Lagoon are essentially sea-water which has been concentrated by evaporation.

Sand-sized sediments have been derived from the Pleistocene and Recent dunes and from shell remains of lagoonal organisms. Muds have accumulated mainly in the deeper central portions of the lagoon, where they attain a thickness of at least 11 feet. Those of the Northern Lagoon are mainly argillaceous clays of detrital origin. The surface muds of the Southern Lagoon contain between 40% and 90% calcium carbonate, in the form of mixed aragonite and magnesian calcite. Subsurface muds have a lower carbonate content composed almost entirely of magnesian calcite.

It is considered that the aragonite and magnesian

calcite have been precipitated by the evaporation of lagoon waters. Summer chlorosities exceed 50‰ in the Southern Lagoon while the average summer temperatures are about 20°C. The pH is maintained at a moderately high level, between 8.25 and 8.50, by algal and other plant activity.

Vertical changes in the distribution of aragonite and changes in the organic remains of the lagoon have been used to outline two separate phases of lagoonal sedimentation and the existence of an earlier phase of sheltered marine sedimentation throughout the Coorong. These changes in the lagoonal environment reflect an increasing degree of isolation between the lagoon and the ocean during the development of the present conditions, and are associated with the splitting of the Coorong into the present lagoon, lakes and mud-flats.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University; nor, to the best of my belief, does the thesis contain any material previously published or written by another person, except where due reference is made in the text of the thesis.

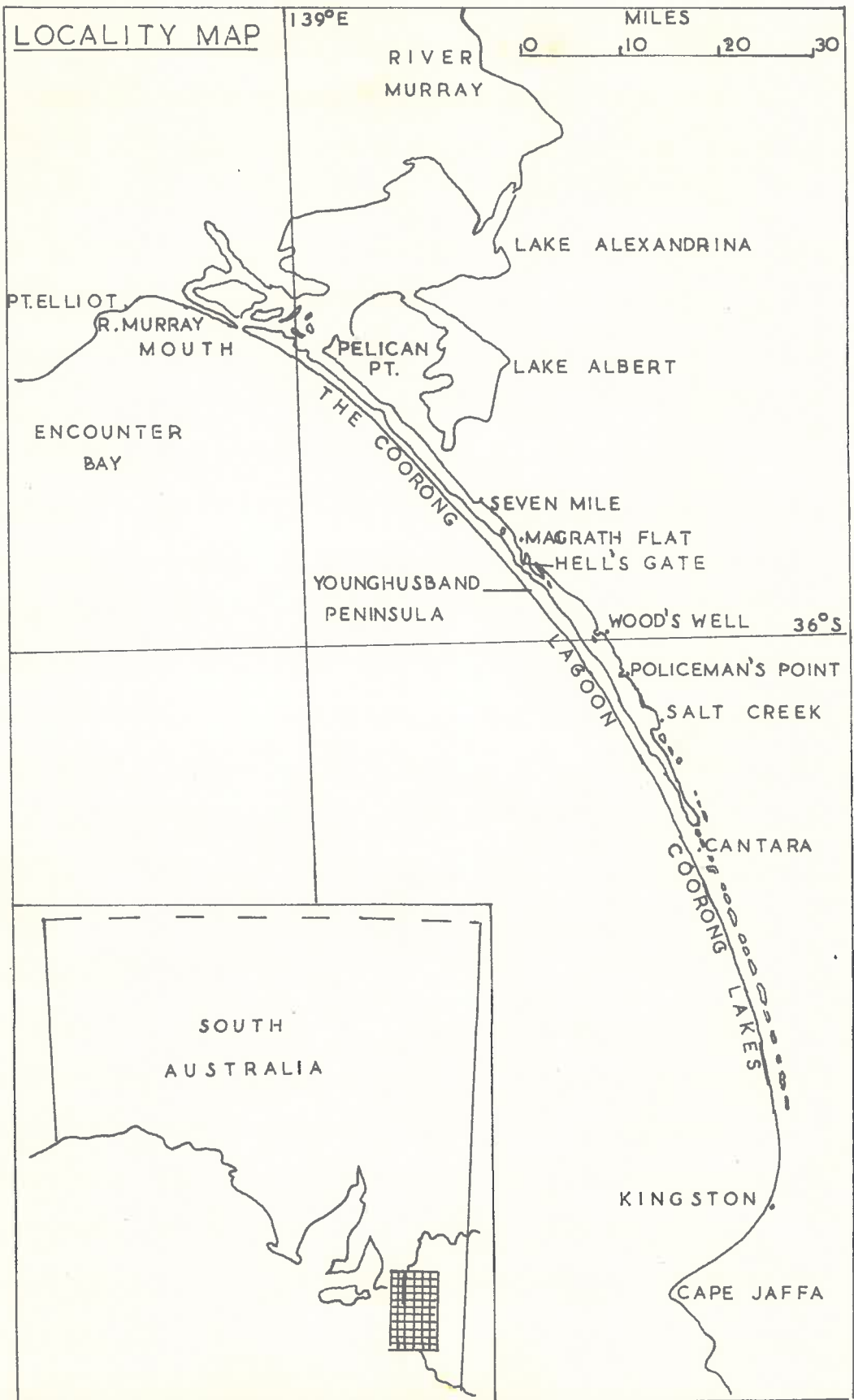
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INTRODUCTION.



INTRODUCTION.

A range of coastal sand dunes extends along the shoreline of the Southern Ocean for a distance of 100 miles north of Kingston, in the Upper South East District of South Australia. The dunes are separated from the mainland by an elongate low-lying area known as the Coorong, which consists of a permanently inundated lagoon, about 60 miles in length, and a series of ephemeral lakes, separated by swampy mud-flats. Within the Coorong, the regional geomorphology, climate and Recent geological history, have created numerous sites in which calcareous muds are forming and being deposited.

Earlier investigations of the southern half of the Coorong have revealed the nature of the sediments and the depositional environments in the lake areas and the southernmost part of the lagoon. The present investigation was directed at ascertaining the nature of the sedimentation in the lagoon and its relationship with the sedimentation in the adjoining areas.

Mawson (1929) discovered that dolomite was present in muds within the Coorong, and considered that this mineral was forming from lake waters. Later investigations by Alderman, Skinner, and von der Borch, (see Reference List), have revealed that a variety of carbonate minerals are present in muds of the Coorong and that these minerals have formed or are forming in the depositional sites. Systematic

investigations of the numerous lakes in the region and the southernmost part of the lagoon have shown that the carbonate minerals occur singly or in pairs within the depositional sites - see Alderman and Skinner (1957), Skinner (1963), von der Borch (1962 and in press) and Alderman (in press). The minerals present are dolomite, magnesian calcite, aragonite, magnesite and hydromagnesite. Radiometric datings reported by Skinner and others (1963) and von der Borch and others (1964) show that the dolomitic and calcitic muds are forming at present, and the same is probably true of the other carbonate minerals.

The depositional sites investigated by these workers are all ephemeral. The lakes contain shallow water for only part of each year, when the water is generally less than 3 feet deep. They contain a relatively thin sequence of sediments, generally less than 3 feet thick. Relevant climatic factors are relatively uniform throughout the Coorong. The water in the lakes is largely derived from local groundwater and rainfall over the lakes, and there is very little surface run-off from the adjacent mud flats. In the waters of the lakes and the lagoon, the ionic ratios of the more abundant elements are generally similar to those of sea water, but the relative abundance of calcium shows some variation. von der Borch (1962 and in press) showed that the principal factors controlling the genesis of the different carbonate minerals were the pH and calcium to magnesium ratio of the lake waters, and the composition of

the local ground waters.

The area examined during the present investigation differs in many respects from the areas described above. The lagoon is a large body of water, permanently inundated over much of its extent, and both the depth of water and the thickness of sediments are greater than in the lake areas. The presence of a single connection to the ocean and that of a large river, the River Murray, at the northern end of the lagoon have imposed environmental controls not found in the lake areas.

The Coorong Lagoon is the northern part of a transitional region which has both marine and non-marine environmental characteristics. Within the lagoon, the environmental factors which produced the region of carbonate mud deposition, (chiefly an absence of detrital sedimentation and favorable water compositions), gradually change, and the character of the sedimentation changes markedly. Northward along the lagoon, the region of carbonate deposition grades into a region in which detrital sedimentation is the predominant process.

This investigation is a contribution to a larger investigation of the sedimentation in the Coorong. In this respect, the aims of this investigation have been

- (1) to outline the northern limit of the regional extent and the environmental controls of the carbonate deposition in the Coorong, and
- (2) to relate the record of Recent environmental

changes preserved in the lagoonal sediments to the development of the Coorong and its diverse carbonate depositing environments.

In its own right, the lagoon is an interesting, and, perhaps, an important environment. Various writers have postulated environments similar to that of the Coorong Lagoon in the stratigraphic record. A further aim of this investigation has been to outline the depositional processes that have proceeded within the lagoon, and to relate these processes to the sedimentary record preserved therein. Because of the size of the lagoon and the limited time available, this investigation was largely confined to the southern half of the lagoon, which encompassed the primary aims. The northern half was briefly examined, and a broad assessment of the whole lagoon obtained.

PREVIOUS INVESTIGATIONS.

The introductory remarks above outline the extent of investigations which have been specifically directed at the study of the sediments and depositional conditions in the Coorong. The forthcoming papers of Alderman and von der Borch contain complete summaries of these investigations. More recently, Peterson and von der Borch (in press) have reported the occurrence of modern inorganic chert in some of the Coorong lakes.

Investigations of the adjacent areas have yielded some information on the Coorong region. Robertson (1929)

reported a rise in the pH of lagoon waters from 8.2 near the mouth of the River Murray to 8.8 near Seven Mile Point in the northern half of the lagoon. Physiographical and geological features of the Coorong and of the adjacent areas have been described and interpreted by several authors, notably Tindale (1933, 1947 and 1959), Ward (1941), Crocker and Cotton (1946), Crocker (1946), Hossfeld (1950), Sprigg (1952 a and b, 1959), de Wooy (1959 a), Correll and Lange (1963) and Blackburn and others (1965).

METHODS.

Field operations on the lagoon were carried out from a small dinghy. Sample locations were determined by compass bearings from landmarks. Because of the absence of hydrographic charts and detailed maps of the shoreline, a base map was drawn up from aerial photographs, but there is no lateral control on this map. The topography of the lagoon floor was determined from soundings made with a graduated wooden pole along predetermined traverses. Water levels quoted, other than those specifically related to high water level and those quoted in discussions of water samples, are referred to low water level of the lagoon. The oscillations in lagoon water level are seasonal and there is no perceptible tidal variation along most of the lagoon.

Owing to the presence of wind-induced variations, which may produce water level differences along the lagoon, references to this datum involve a possible error of ± 6 inches. An arbitrary zero level was selected at 7 feet below the top of an iron pole located close to the low water strandline at a landing site due north of Stony Well Island.

Sediment samples were collected with a small clam-shell grab sampler and with a manually operated piston coring device, which consists of a wooden pole to which plastic tubes of $1\frac{1}{2}$ inches internal diameter, were fitted.

Water samples were collected with a weighted bottle, fitted with a cap which could be released at any desired depth. Temperatures were recorded at the time of

sampling. pH was measured by a pH electrometer, at the time of collection or after returning to the shore, depending on weather conditions.

In the laboratory, cores were split after extrusion. After a controlled period ^{of} drying, they were photographed, and examined under a binocular microscope. Samples from selected intervals were treated with hydrogen peroxide, and washed through a 240 mesh BSS sieve. The coarse fractions were subjected to further microscopic examination. Sand sediments were treated with hydrogen peroxide when necessary, and the grain size distribution determined by sieving through a set of BSS sieves.

X-ray powder diffraction photographs of the fine fraction from selected samples were used to determine the mineralogy of the muds. A camera with diameter 57.3 mm and either CuK_α or CoK_α radiation were used. A few samples were examined with an electron microscope, and electron photomicrographs obtained. The total carbonate content of the fine fraction of selected samples was determined by finely grinding about 0.5 gm, and adding a known quantity of standardised 0.1 N hydrochloric acid. The excess acid was determined by titration against standardised sodium carbonate solution.

The chloride ion content of the lagoon waters was determined by the Mohr titration method, and is expressed throughout as chlorosity. Calcium and magnesium contents were determined by compleximetric titration with EDTA,

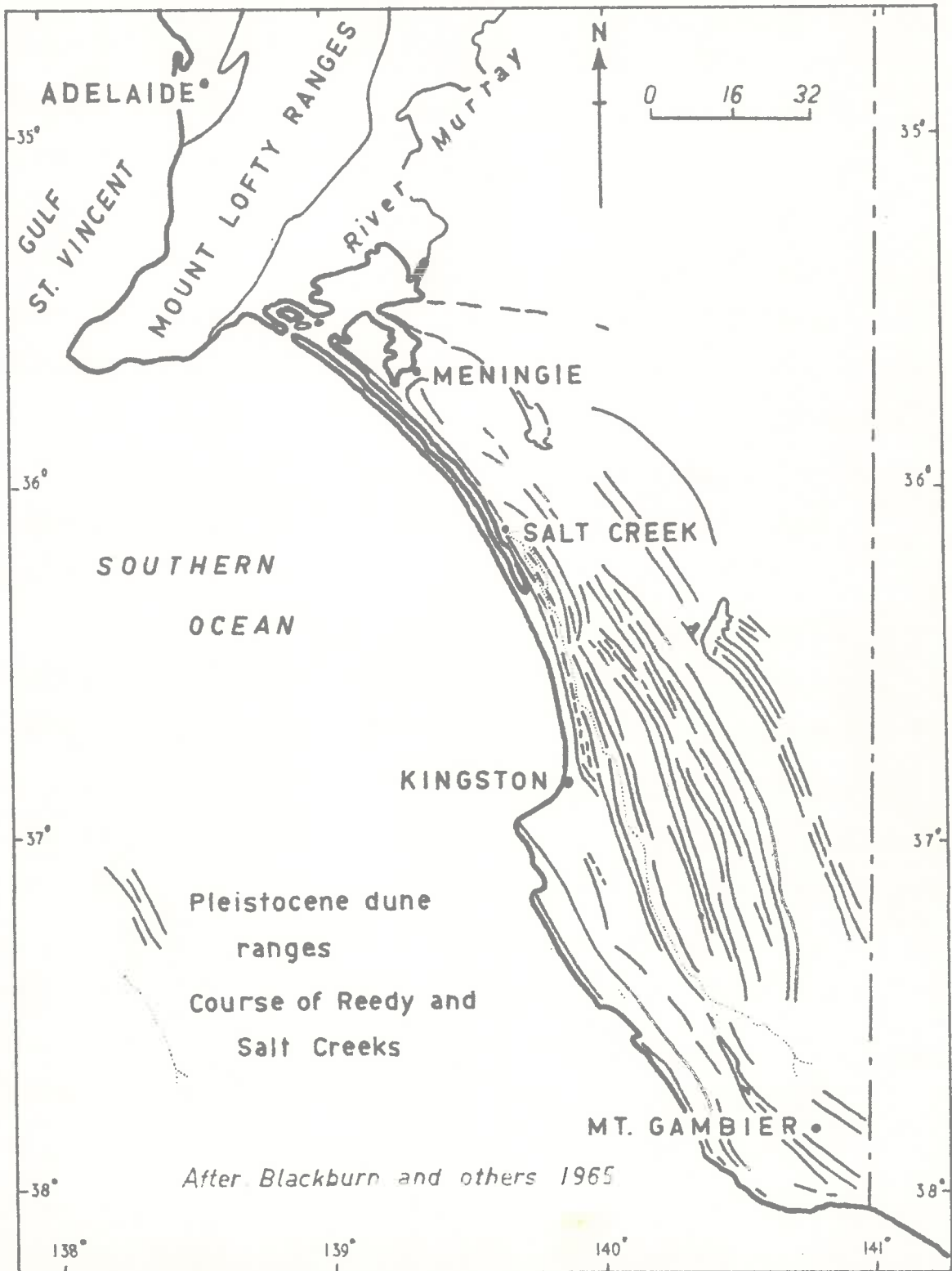
using ammonium purpurate and "Eriochrome Black T" as indicators, as described in "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." American Public Health Association, New York. The content of sulphate ion was determined gravimetrically as barium sulphate.

The magnesium content of the calcite in lagoonal muds was estimated by using a graph of $d(112)$ spacing vs. mol % CaCO_3 in the calcite, as described by Goldsmith, Graf and Joensuu (1955). As the $d(112)$ spacings have been determined from powder photographs, the estimations are of limited accuracy and have been used only to broadly outline variations in calcite composition.

REGIONAL FEATURES.

FIGURE 1

RELATIONSHIP OF PLEISTOCENE DUNE RIDGES
TO THE COORONG



REGIONAL GEOLOGY AND MORPHOLOGY.

The Coorong is situated along portion of the present western margin of an extensive plain forming the land surface of the Murray Basin, which contains a thick sequence of Mesozoic and Tertiary sediments. The Coorong is located in a section of the basin called the Padthaway Horst or the Padthaway Ridge - see Sprigg (1952 a) and O'Driscoll (1960) - formed mainly of granitic rocks of Palaeozoic (?) age. These are found outcropping in a number of localities, including one within the Coorong near its southern end, and one on the nearby ocean beach. Boulder clays, considered to be Permian glacial deposits, have been encountered in a number of bores above the basement rocks close to the Coorong - see Sprigg (1952 a) and O'Driscoll (1960).

After the regression of the Tertiary seas, much of the surface of the Murray Basin formed a broad plain rising gently inland. During the Pleistocene, the western parts of this plain were subjected to a series of marine transgressions and regressions, generally regarded as a result of world-wide eustatic changes in sea level. To the south and east of Kingston there is a remarkable sequence of long sand dune "ranges", separated by broad and rather low-lying interdunal depressions or interdune corridors (see Fig. 1). The dune ranges are found up to about 50 miles inland, aligned approximately parallel to the present coastline. The ranges have been regarded as strandline accumulations marking the extent of Pleistocene transgressions. The

chronological order of their formation and the correlation of the transgressions with the climatic and sea level fluctuations in other parts of the world have been variously interpreted by Tindale (1933 and 1947), Hossfeld (1950), Sprigg (1952 a and b) and others.

To the north and north-east of Kingston, the dune ranges tend to coalesce, for there has been a northward downwarping during their deposition, see Hossfeld (1950) and Sprigg (1952 a). East of the Coorong, there are dune ranges separated by clearly defined interdunal depressions, but the correlation of these features with those further to the south-east is uncertain. The ranges are probably combinations of the ranges named in the South East by Hossfeld (1950) and Sprigg (1952 a). Along the shores of the Coorong and on islands within the lagoon, the Pleistocene dunes form outcrops of lightly cemented calcareous sandstone or aeolianite, showing a prominent weathering profile which includes a layer of kunkar or caliche.

A belt of largely non-indurated sand dunes, from one quarter of a mile to one mile wide, forms a range along the present coastline of the Southern Ocean between Cape Jaffa and Port Elliot, (see ^{Locality Map} ~~Fig. 4~~). These dunes have probably accumulated within the Recent, marking the maximum extent in this area of the post-Pleistocene world-wide eustatic rise in sea level. The only break in the continuity of this range is near its northern end, at the mouth of the River Murray. South of the river mouth, the dunes form a long

peninsula called Younghusband Peninsula, which is separated from the mainland over a distance of about 60 miles by the Coorong Lagoon. South of the lagoon, the Recent dunes are separated from the Pleistocene dunes by an emerged interdunal corridor, occupied by carbonate mud-flats and numerous playa-like lakes, which forms the southern half of the Coorong.

The term "Coorong" is generally applied to the lagoon and the adjacent lakes, but some have used it as a regional name, incorporating also the adjacent sand dunes and the nearby ocean beach. The word Coorong is derived from an Aboriginal word meaning a place of shallow water (Tindale, personal communication). In this investigation, it will be used to cover the lagoon, the lakes and the swampy mud-flats separating these bodies of water, within the interdunal depression between the Recent dune range and the mainland. The Coorong is considered to stretch south from Pelican Point to Kingston. The lagoon will be referred to as "the Coorong Lagoon" or simply "the lagoon".

Along the eastern side of Younghusband Peninsula, between Needles Island and Wataleera Bay, (see Fig. 17), a series of disconnected kunkarized dunes, similar to those of the mainland, are found in a narrow belt which reaches about 1600 feet in width. These outcrops, and others within the lagoon, indicate that the Recent dune range and the lagoon are situated, at least in part, on a site formerly occupied by Pleistocene dunes.

CLIMATE.

The average annual rainfall in the Coorong area is about 20 inches, most of which falls between May and October, inclusive. Around Lake Alexandrina there is an evaporation rate of over 36 inches per annum, with an evaporation of 24 inches between November and February, inclusive (McIntosh (1948)). The average winter temperature is about 10° C and the average summer temperature about 25° C. The prevailing wind direction is from the south-west, which is normal to the alignment of the coastline and the lagoon.

DRAINAGE.

Before the construction of an artificial drainage system in the area south and east of Kingston, surface water from that region used to flow north-westwards along the interdunal depressions. Much of this water eventually flowed into the Coorong, mostly through Salt Creek. A series of stepbanks were constructed to stop the north-westward passage of water, and drains were cut through the dune ranges to carry the water directly to the sea. The stepbanks and drains constructed about 1920 probably stopped an annual discharge through Salt Creek, but in years of high rainfall water still escaped along this route. Further construction and enlargement of drains, particularly during the 1950's, have made it most unlikely that water will flow from Salt Creek again. Because of the sandy terrain east of the lagoon, there are no other streams entering the

Coorong.

At its northern end, the Coorong Lagoon joins the outlet channels from Lake Alexandrina, through which the River Murray flows to the sea. This river is the largest in Australia and its catchment area covers a large portion of the continent. During summer and autumn months, the rate of river flow is very low. A high rate of flow follows winter rains in the catchment area and the melting of snows in the Great Dividing Range. Flood peaks may develop, usually reaching the mouth of the river in spring or early summer.

A series of barrages have been constructed to the north of Pelican Point and further upstream in order to maintain a relatively stable water level during the period of low river flow. These do not greatly affect the timing or duration of strong river flow. Reservoirs and other similar constructions upstream have altered the intensity of floods and strong river flow. They may therefore have led to change in the amount of river water which enters the Coorong Lagoon, but the extent of this change is not known. As will be shown later, the entry of river water into the lagoon is greatly controlled by the lagoon's morphology and its own water level oscillation, so that these changes may be of relatively small extent.

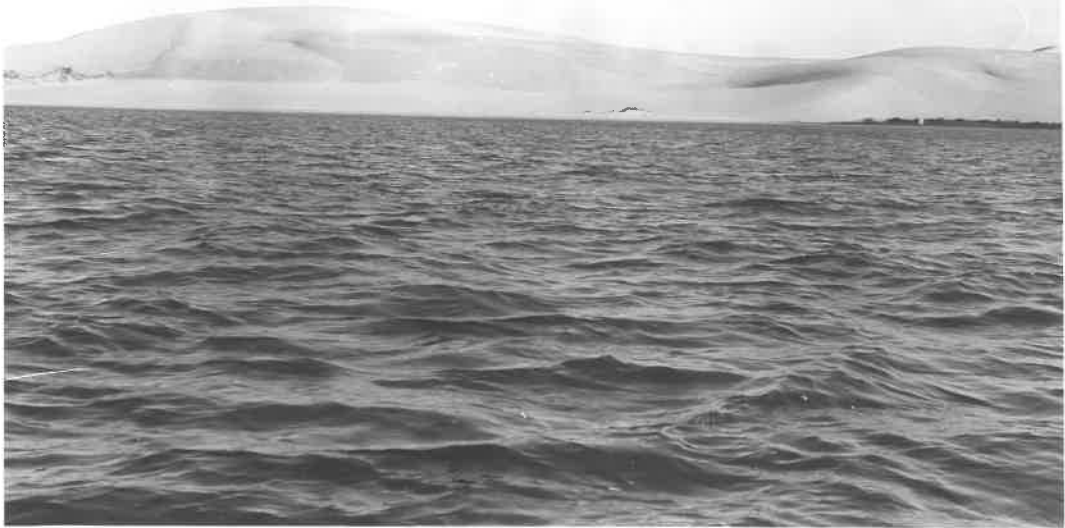
SAND DUNES BORDERING THE COORONG LAGOON.

PLATE 1.

Recent sand dunes along the western shore of the lagoon,
near Dodd's Landing Point, in the Northern Lagoon.

A. Broad, rounded drifts.

B. An elongate steeply peaked ridge, trending SW-NE.



RECENT DUNES1. TOPOGRAPHY

South of a point about 20 miles north of Kingston, the Recent dunes form a regular series of low sub-parallel ridges, about 40 feet high - see Sprigg (1952 a). Adjacent to the lagoon, the dunes form a more disordered array of higher rounded hillocks, 50 to 100 feet high, mostly covered by vegetation and traversed by moving sand drifts, which show an alignment along a SW to NE direction. The drifts may be smoothly rounded and broad (up to one mile wide), with gentle windward slopes and steep slip faces, or they may be in the form of narrow, steeply peaked ridges, (see Plate 1). Most of the drifts have their origins in deflated areas close to the western shoreline. As they move to the north - east, they smother vegetation in their paths and widen into broad fan-shaped and tongue-like forms.

2. COMPONENT MATERIALS

The dune sands are well to very well sorted and are predominantly of medium and fine sand size, (see Fig. 14 and Table 3). They have a cream colour, due to the presence of yellow-brown calcareous grains. Calcareous grains constitute 35 to 60% of the grains in the samples collected (see Table 3). Sprigg (1952 a) reported a slight northward increase in the carbonate content and the mean grain size of the sands along the ocean beach, but a systematic sampling of the beach and dune sands was not attempted in the

PLATE 2.

Midden deposits, composed almost entirely of shells of
Plebidonax deltoides. Scale is 24 in. long.



present investigation. The calcareous grains are rounded to well rounded shell fragments. In the medium and coarse sand fractions the calcareous grains are tabular, but those in finer fractions are generally equant. The grain surfaces are moderately polished, but covered by a scattered, light frosting. The quartz grains are most abundant in the fine and very fine sand fractions, and are of equant shape. Medium and coarse quartz grains are rounded and subrounded, while those of finer size are subrounded to subangular. The grain surfaces are fairly smooth and glassy, with a scattered and very light frosting.

The dune sands show very well developed stratification, with laminae outlined by variations in grain size. In laminae containing an abundance of tabular grains, the grains show a strong tendency to be horizontally oriented. Large scale cross-bedding is revealed in deflated areas, and the steeply dipping slip faces show strongly inclined stratification. The stratification in dune sands shows faulting in some areas where there has been subsidence of the sub-stratum (see Fig. 11 and page 178).

3. MIDDEN DEPOSITS

Accumulations of food shells left by Aborigines form midden deposits which may cover large areas of the Recent dune surface, (see Plate 2). The middens are found at both high and low elevations, generally on or very close to the surface. They are readily differentiated from the emerged beach deposits which will be discussed in the following pages,

for they are almost exclusively composed of tests of the lamellibranch Plebidonax deltoidea (Lamarck 1818) and very rarely contain the most abundant species of beach deposits, Nectra rufescens (Lamarck 1818). They also lack the variety of small gastropods found abundantly in the beach deposits. Some middens contain small groups of fire-blackened limestone boulders, charcoal, pieces of flaked flint, and rare pieces of granite.

Middens are found along both shores of the Coorong Lagoon, and in a few places the deposits are being eroded by the lagoon waters. A few shells of P. deltoidea are found in lagoon sediments, mainly lying on the surface, but occasionally mixed into beds of lagoonal shell material. These have probably been transported from the ocean beach by Aborigines, for other characteristic remains of the ocean beach fauna have not been found and P. deltoidea is a lamellibranch characteristic of open ocean beaches. A few midden deposits along the eastern shoreline of the peninsula near Tatunda Bay are composed of remains of Mytilus planulatus (Lamarck 1819), one of the large lamellibranchs found in the lagoon, but other lagoonal shells have not been seen in midden deposits.

4. POST-DEPOSITIONAL CHANGES

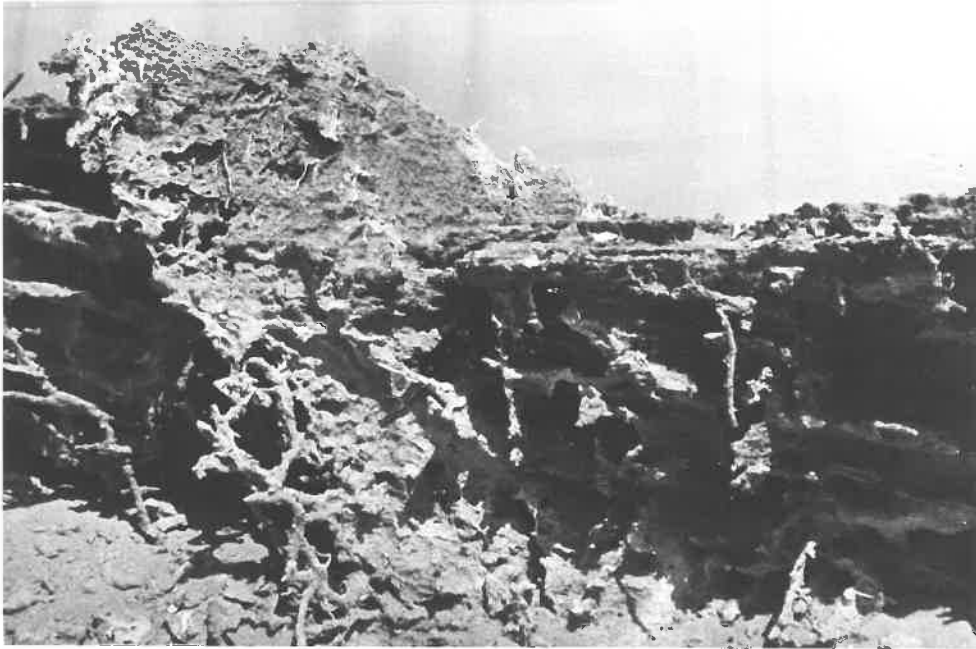
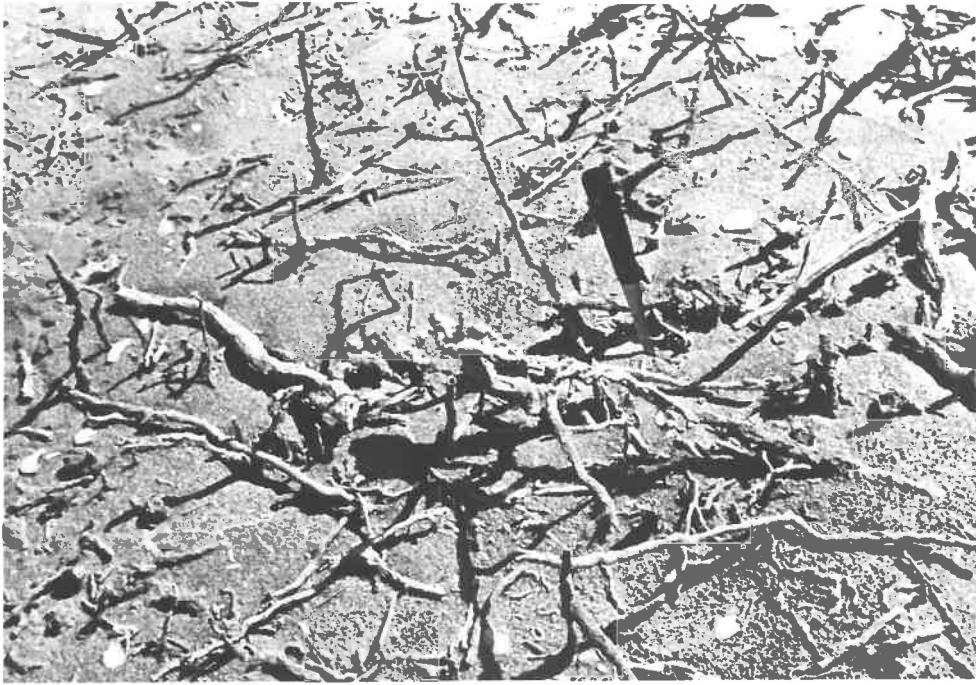
The Recent dunes have been extensively covered by vegetation in the past. The large drifts now observed appear to be of fairly recent origin, and are actively destroying the cover of vegetation over large areas.

PLATE 3.

Secondary calcareous deposits in the Recent dunes of
Younghusband Peninsula.

A. Rhizocretions. Knife is 6 in. long.

B. Lightly cemented aeolian sands, showing localisation
of calcareous cement along a joint plane which
cuts the near-horizontal lamination of the friable
aeolianite.



A black, sandy soil forms a layer up to 18 inches thick in some areas where deflation has revealed the internal structure of the dunes. In a few areas this soil horizon has been covered by a later deposit of sand, which has been stabilized by vegetation, but on which no soil horizon has developed. Many of the vegetated dunes do not show a soil horizon, and it is possible that there is a dichotomy in the ages of the vegetated dune surfaces.

The surface sands of the dunes are not cemented, but deflation has revealed that calcareous cement has been deposited well below the surface in some dunes, producing a lightly cemented sandstone. In many deflated areas, rod-like and tubular structures form a rootlike network, or project vertically above the deflated surface in groups of isolated rods, (see Plate 3). These are similar to the rhizcretions described by ^Kindle (1923 and 1925), and the presence of plant material within a few of the structures suggests that they may have been formed by the localization of carbonate deposition around plant roots. The rhizcretions are found on dome-shaped and undulating surfaces, often at high elevations. The shape of the surface, which they now partially protect from deflation, suggests that it reflects the outline of the pre-deflation dune surface, and that they were formed close to the older surface. Rhizcretions are commonly found concentrated in slightly deflated areas which surround or are adjacent to remnant patches of black soil. This, too, suggests that

they were formed close to the dune surface and that they were formed in areas above which vegetation existed for a relatively long period.

In areas which have been more extensively deflated, commonly to within a few feet of sea level, more widespread cementation of dune interiors has been revealed. Outcrops of lightly cemented sandstone are found, in places extending over several acres. The cement has been localized along particular bedding planes, and differential erosion has produced strongly etched outcrops, (see Plate 3). In a few places, the deposition of cement has been localized along joint planes which cut the bedding planes at high angles, (see Plate 3).

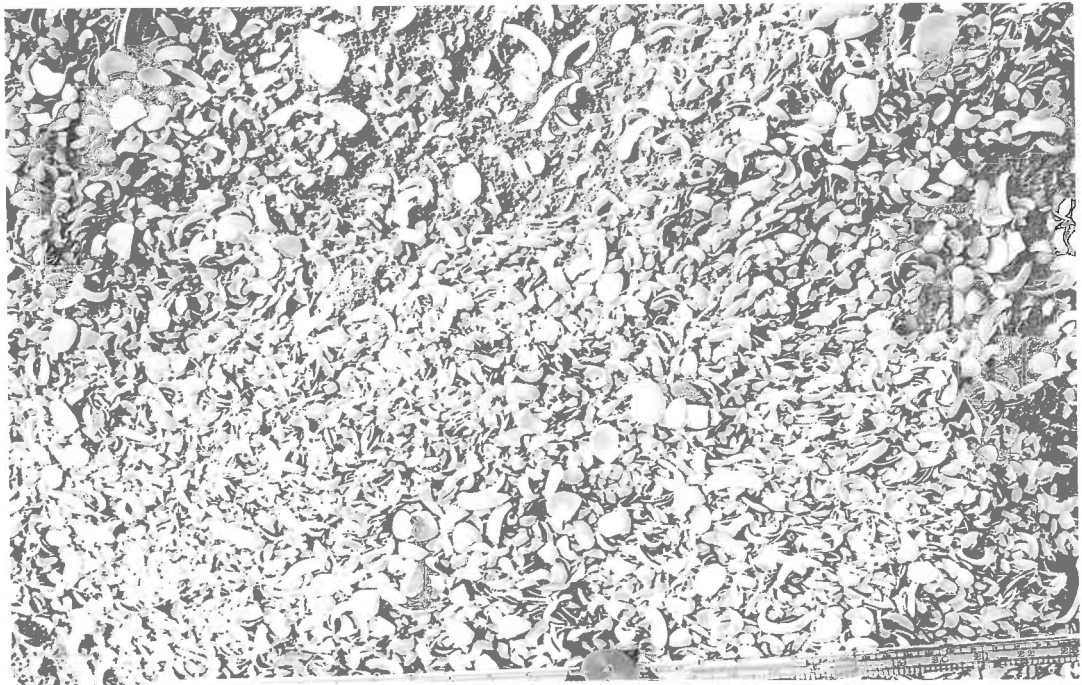
The exposure of dune interiors in which there has been widespread cementation is far more common along the seaward side of the northern half of the peninsula than in the southern half. In the north, the ocean is actively encroaching on the dunes (see later) and the shoreline has moved eastward. Older parts of the Recent dunes are now in the near-shore area, where deflation by on-shore winds is most intense, so that large areas of the interiors of these older dunes have been exposed. In the southern half, the shoreline has not moved eastwards (see below). There, the deflation of near-shore sites is taking place in areas where the dunes are probably of more recent age, so that the development of widespread cementation has not yet occurred, and the deflated sites reveal largely unconsolidated sands.

PLATE 4.

Emerged ocean beach ridge of Recent age along the western side of Youngusband Peninsula, south of Wataleera Bay.

A. A shell-covered area with one prominent ridge, east of the coastal dune-ridge.

B. Coquina of rounded shell fragments, mainly Mactra rufescens with some Plebidonax deltoides.



5. CHANGES IN SHORELINE LOCATION

Along the western side of Youngusband Peninsula, there are indications that the location of the ocean shoreline has changed. Along the northern half of the peninsula, north from near Hell's Gate, the whole of the shoreline appears to be moving eastwards. South of Hell's Gate, the shoreline appears to be stationary at present, but there is evidence that it has moved westwards in the past.

The shoreline south of Hell's Gate is lined by a continuous low dune ridge, stabilized by a thin cover of vegetation. South of a point across the peninsula from Wataleera Bay, a series of parallel beach ridges is found to the east of this dune ridge, (see Plate 4 and Fig. 17), indicating that there has been a regression in this area. The ridges are composed of sand overlain by a capping, a few inches thick, consisting of close-packed and imbricated shell material. This coquina is similar in appearance to the shell accumulations of the present ocean beach, and contains the same fauna. The ridges are confined to a discontinuous belt, 500 to 800 feet wide, broken at intervals by low dunes, which are, in part, extensions of the coastal dune ridge. The ridges show no deflection as they approach the discontinuities, indicating that the beach ridges are overlain by, and pre-date the dunes.

It is considered that the beach ridges were formed in rapid succession during a regression of the shoreline, and that the regression was sufficiently rapid to prevent the

PLATE 5.

Eroded dune facing the Southern Ocean, due south of
Dodd's Landing Point. The ocean has truncated a
midden-covered surface and exposed lightly cemented
aeolianite (marked by arrow).



development of a continuous coastal dune ridge until the present location of the shoreline was reached. Along the present shoreline, a continuous dune ridge has accumulated above the beach. It shows no indication that it is being eroded from the west, and shows little tendency to move inland.

Along the ocean beach north from the vicinity of Hell's Gate, the coastal dunes have been eroded to form steep banks several feet high, (see Plate 5). There are numerous localities where the sea water washes into low swales at times of storm tides and the higher swales appear as hanging valleys in the eroded dunes above the beach. Outcrops of a lightly cemented sandstone, identical with that occurring in the interiors of deflated dunes, were found in one locality on the ocean beach, indicating that the present shoreline is situated on a site which was previously covered by a dune. This outcrop, and the extensive exposures of the interiors of older dunes close to the western side of the peninsula, indicate that the eastward movement of the shoreline in the northern half of the peninsula has been in progress over a considerable period of time and that the presence of eroded dunes along the beach is not just a temporary result of winter storms.

These adjustments to the position of the coastline indicate that changes have occurred in the factors which control the position of the shoreline which will be in equilibrium with the Southern Ocean in this region. The

changes may have been simultaneously initiated responses to the same environmental change, or they may have been initiated at different times and by different causes. The fact that the process of shoreline relocation does not appear to be in progress at the present time in the southern area does not necessarily negate the first of these possibilities. It is possible that the relocations were simultaneously initiated, and that the restoration of the coastline to a position in equilibrium with the new conditions was more rapidly achieved in the southern area, by accretion, than in the northern area, where erosion was necessary.

The following are possible causes for the changes in the location of the coastline:

- (i) the shoreline has been gently tilted downwards to the north, in response to movement of the underlying basement rocks;
- (ii) there have been changes in the physical characteristics of the adjacent ocean, e.g. a change in the direction from which waves most commonly approach the shore;
- (iii) there has been a change in the rate of supply of sediment to different parts of the beach;
- (iv) there have lately been eustatic changes in sea level.

There is no direct evidence to indicate the correct explanation, but the regional geology suggests that tilting of the coastline is the most likely explanation, at least

for the transgressive nature of the northern part of the coastline. Mossfeld (1950) and Sprigg (1952 a and 1959) concluded that during the Pleistocene there was fairly continuous relative downwarping, northward from the vicinity of Mount Gambier towards the Mount Lofty Ranges (see Fig. 1). This movement may have continued into the Recent, and if so, it would affect the present ocean coastline. The emerged beach ridges, if due to this process, would indicate that there was differential movement relative to sea level in the vicinity of the Coorong Lagoon. The presence of emerged lagoonal deposits along the shorelines of the lagoon (see later) suggests that the emerged ocean beach deposits were formed by a change in sea level relative to the land. As discussed in a later section considering the evolution of the lagoon, it is considered that the most likely explanation of these deposits is that there has been a slight marine regression due to tectonic uplift of the area along the southern half of the lagoon.

1. TOPOGRAPHY

The Pleistocene dunes along the margins of the Coorong show a topography similar to that of the Recent dunes, but with a more subdued relief. Some areas show a well developed pattern of parallel dune ridges, aligned approximately SE to NW, similar in appearance to the Recent dune ridges north of Kingston. Most areas, however, do not show any ordered arrangement of the dunes, other than some short ridges aligned along a direction from SW to NE, similar in appearance to the dune drifts on Youngusband Peninsula. The dunes were formerly covered by a thick growth of scrub, but they have been cleared over wide areas and sown to pasture.

The surface undulations are subdued when compared with those of the Recent dunes. Along much of the lagoon shoreline, and, in some areas, up to one half of a mile to the east of the lagoon, the surface shows only very gentle relief. Further inland the surface is higher and shows a more accentuated relief, and, as outlined below, it is likely that there are at least two superimposed dune ranges in the area east of the lagoon.

The outline of the present surface of the Pleistocene dunes is due to the widespread control of the topography by a hard layer of kunkar, which acts as a base level to erosion, and has been rarely breached away from the lagoon

shoreline. The kunkar reflects the original dune surfaces, but in a subdued fashion, probably as a result of factors which controlled its development. Removal of much of the material which originally covered the kunkar has led to the development of a land surface which, over wide areas, follows the gently undulating kunkar layer.

2. STRUCTURE

The regional distribution pattern of the Pleistocene dunes in the South East district of South Australia suggests that the range bordering the Coorong may be a combination of two or more of the ranges which are separated further to the south east. The topography of the area adjacent to the Coorong also suggests this, and during the course of this investigation, remnants of an emerged ocean shoreline were found within the Pleistocene dunes. This shoreline can be related to the subdivision of the near-Coorong dunes suggested by de Mooy (1962).

(a) Topographic Subdivision.

de Mooy (1962) recognized the presence of two types of topography in the Pleistocene dunes east of the Ephemeral Lagoon, and on this basis he divided the dunes along the Coorong into two units. He grouped the dunes immediately east of the Ephemeral Lagoon into a unit designated as "Unit 3", which is "typified by a topography of beach ridges parallel to the coastline". He considered that these dunes were terminated by the lagoon near Salt Creek. Slightly to

the east is a higher "undulating range with no special trend", which he designated as "Unit 4". This unit continues northward through the vicinity of Magrath Flat, and ultimately becomes part of the "Bonney dune landscape", which he considers grew northward in three stages from Magrath Flat to Pelican Point.

The aligned dune ridges of de Mooy's Unit 3 can readily be traced along the eastern side of the Ephemeral Lagoon as far north as the "Hydromagnesite Lake", (see Fig.). In the ridged area, von der Borch (1962) described elongate ephemeral lakes, aligned in the interdunal depressions. But in the area immediately to the south-east of Salt Creek Point, the topography is very gently undulating, and shows no ordered arrangement. Three large lakes in this area show no particular orientation. This area is similar in appearance to the areas of low and subdued relief adjacent to the lagoon in areas such as that around Trevarrow's Point and in the areas of Pleistocene dunes on Younghusband Peninsula. It is considered that the ridges of de Mooy's Unit 3 grade into an area of very subdued and disordered relief in the vicinity of the Hydromagnesite Lake and that this group of dunes extends northward into the area now occupied by the lagoon. Here, it has been dissected, and only remnants are now found on each side of the lagoon and on the mid-lagoon islands.

(b) Emerged Shorelines.

A few hundred yards upstream from the road bridge over

PLATE 6.

The emerged ocean beach of Pleistocene age upstream from the road-bridge over Salt Creek. The base of the coquina is outlined and dips westwards above cross-bedded aeolianite. To the right, the coquina is overlain by off-shore deposits of laminated sandstone and coquina (a).



Plate 6

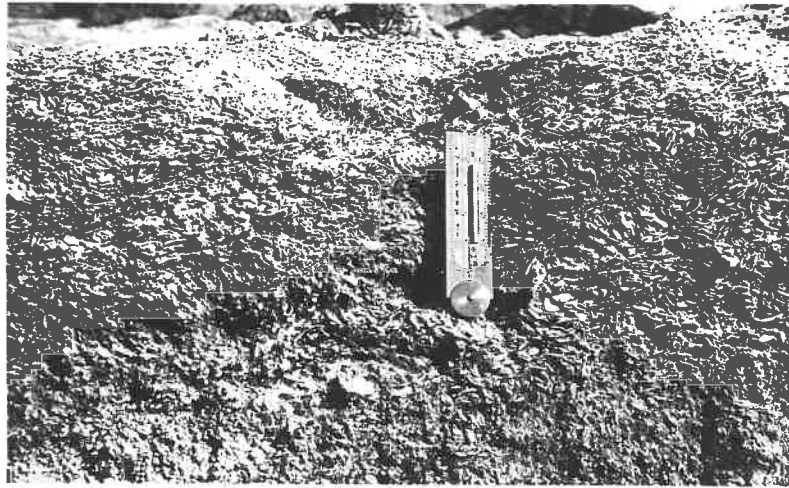
PLATE 7.

The Salt Creek Pleistocene beach.

- A. The basal coquina, showing large shell fragments and rounded pebbles of aeolianite, resting on fine grained aeolianite. Scale is 12 in. long.

- B. Coquina of close-packed and sorted, rounded shell fragments. Scale is 6 in. long.

- C. Coquina of un-worn shell material at the top of the off-shore sequence. The surface capping is kunkar. Scale is 12 in. long.



Salt Creek, the banks and the bed of the creek contain a well exposed cross-section of an emerged ocean beach deposit, which lies unconformably above cross-bedded aeolianite. The basal contact of the emerged section dips westwards and marks a marine transgression which led to the deposition of an onlapping sequence above the aeolianite, (see Plates 6 and 7).

The basal parts of the sequence consist of a coquina formed of large, rounded shell fragments, containing boulders and pebbles of the underlying aeolianite. This portion of the sequence is evidently an ocean shoreline accumulation of abraded and sorted material. It is conformably overlain by a succession of laminated sandstones and coquina containing only unworm shells, which are generally not fragmented. This portion of the sequence is considered to be an accumulation of marine sediments deposited in shallow water seaward of the ocean shoreline of that time.

North of Salt Creek, coquina and shelly sandstones are found as isolated outcrops within the Pleistocene dune area (see Fig. 17). Although the outcrops are small and widely separated, they are all located along a line which passes through the emerged shoreline at Salt Creek and it is considered that they outline a single Pleistocene transgression. The line of emerged deposits can be traced as far north as a locality slightly north of Wood's Well homestead, but it appears to be approaching the lagoon shoreline, and may be

Plate 8.

The emerged Pleistocene ocean beach at the Seven Mile locality.

A. Laminated calcareous sandstones dipping westwards.

B. Very coarse and fine grained calcareous sandstones, showing rill (?) marks on the surface of the fine sandstone



cut by the latter for no outcrops were found further north.

The high dunes of de Mooy's (1962) Unit 4 in the region between Wood's Well and Salt Creek may have accumulated at the time of the transgression which produced the emerged shoreline, for they are mostly found to the east of the shoreline. The areas of lower and more subdued relief, which appear to be northward continuations of de Mooy's Unit 3, lie to the west of the emerged shoreline, and may be of younger age. However, this is not certain, because there are no exposures which show the relationships between the shoreline deposits and the dunes to the west.

There are two localities in which beach-rock of emerged ocean shorelines is well exposed along the eastern shore of the lagoon, (see Fig. 17). These exposures, which are about 20 miles apart, are far removed from the emerged shoreline described above, so that the relationship between these three deposits is uncertain. One is a mile long exposure on the lagoon shore to the south of the Seven Mile, (see Plate 8), and the other stretches south of Pelican Point. The beach-rock at the Seven Mile locality is covered at its northern end by a layer of kunkar. The enclosed lamelli-branch fauna is similar to that of the Salt Creek emerged ocean beach. Plebidonax deltoides, which is abundant along the modern ocean beach, is absent. The Seven Mile sequence is probably of Pleistocene age, but whether it can be correlated with the Salt Creek sequence is not known. The emerged deposits at Pelican Point may be of more recent age,

PLATE 9.

Pleistocene dunes.

- A. Cross-bedding in un-weathered aeolianite, 1 mile north-west of Wood's Well.
- B. Undulating surface layer of laminated kunkar, $\frac{1}{2}$ mile north-west of Wood's Well.
- C. Kunkar as blocks and laminae, with vein-like projections extending into the underlying pink sand. 1 mile north-west of Wood's Well.



for they contain a fauna similar to that of the modern ocean beach along the western side of Youngusband Peninsula.

3. COMPONENT MATERIALS.

(a) Unweathered Aeolianite.

The Pleistocene dunes have been extensively altered by weathering, particularly south of Magrath Flat. Erosion along the lagoon shoreline has exposed the unaltered dune interiors thus contributing fresh detritus to the lagoon sediments. The unweathered rock is an indurated calcareous sandstone or aeolianite, cemented by sparry calcite, which forms an interstitial mosaic of clear crystals up to 0.05 mm across. The aeolianite is commonly laminated, and often shows large-scale cross-bedding, (see Plate 9).

The sands are of similar composition to the Recent dune sands, but contain a slightly lower proportion of calcareous grains, (20% to 40%). The calcareous grains have been partly recrystallized, for many show patches of sparry calcite replacing the original organic structure.

In a few cliff-line exposures, the aeolianite is strongly indurated at the exposed faces, but is friable in road cuttings a few yards away, indicating that there has been case hardening of natural exposures.

(b) Weathering Profile.

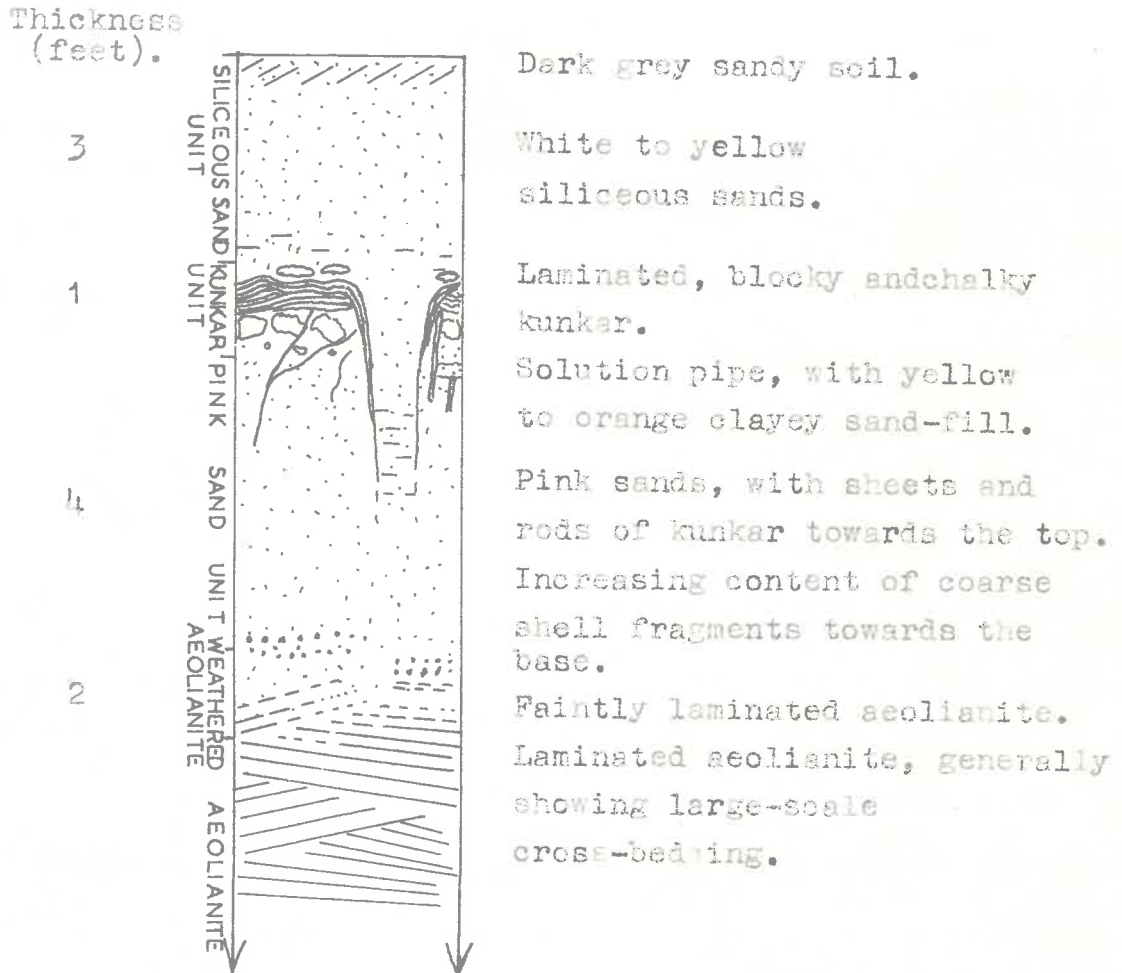
Weathering of the Pleistocene aeolianite has led to large-scale reorganization and redistribution of its calcareous components and has produced a weathering profile

which shows an ordered sequence of distinctive units. This sequence has been modified in many sections by the removal of its uppermost parts, duplication of part or whole of the profile, or by the omission of one or more units. The products of the weathering process have been eroded from wide areas, and some of the removed material has been deposited in the lagoon, where it has strongly influenced the composition of some of the lagoonal sediments. The nature of the weathering profile has controlled much of the topography of the lagoon floor as well as some of the sedimentary processes within the lagoon.

In many localities, particularly in the areas of subdued relief near the lagoon, the highest unit shown in the weathered sequence is a layer of kunkar. Parts of the kunkar are covered by a few inches of dark grey, sandy soil, but this is considered to be a wind-blown deposit which has accumulated after the kunkar was exposed. In most localities, the kunkar is overlain by a bed of siliceous sand. In places these sands have been redistributed by wind action and it is possible that they are entirely an aeolian deposit not related to the kunkar. However, the widespread occurrence of siliceous sands above the kunkar, their presence in the solution pipes which penetrate deep into the weathering profile, and their presence above the lowermost kunkar horizon in sections showing duplicated profiles suggest that they are an integral part of the weathering profile of the aeolianite. Figure 2 illustrates

Figure 2.

A typical weathering profile in the Pleistocene dunes.



what is considered to be the basic weathering profile in the aeolianite along the shores of the Coorong.

(1) Siliceous Sand Unit.

The topmost unit of the sequence consists of yellow to white, and occasionally red, siliceous sands, which generally contain less than 1% calcareous grains, feldspar, ilmenite and other accessory minerals. The grains are predominantly of fine and very fine sand size, (see Table 3). Towards the base of the unit, the proportion of finer material increases and clay-sized calcite is found. Between 60% and 80% of the quartz grains are angular to subangular, with pitted surfaces and irregular outlines, while the remainder are sub-rounded to rounded, with slightly frosted surfaces.

The sands show no stratification other than that shown at the top of vegetation-covered sections, where a dark grey soil forms a layer a few inches thick above a zone of white sand. A few sections show a buried soil layer, indicating that the sands have been reworked by wind action. The thickness of the siliceous sand unit ranges up to about 20 feet, but, owing to the possibility of reworking, its original thickness, which was probably variable, is not known.

The basal contact between the siliceous sand unit and the underlying kunkar is sharply defined, but is commonly of irregular outline, following undulations of the kunkar surface. Where solution pipes are present

in the profile, they are filled with siliceous sand, which has a high content of clay (up to 30% - see Table 3). By means of these pipes the siliceous sand unit extends below the kunkar layer into the pink sand unit, (see Fig. 2).

(11) Kunkar Unit.

Below the siliceous sand unit is a layer of indurated to chalky kunkar, a form of limestone also known as caliche, travertine, travertine kunkar, oalcrete, surface limestone and several other names. The kunkar in the Coorong region varies from chalky sands to hard limestone, and is colored white, pale brown or pale pink. The hard form is found as nodules, small boulders, or as extensive sheets and commonly shows a finely crenulated lamination of alternating white and pale brown laminae, (see Plates 9 and 10). The nodular masses show some lamination, but they do not show the extensively developed concentric lamination found in kunkars elsewhere in South Australia. The kunkar layer is mainly a few inches thick, but it may be up to two feet thick, while in some sections it appears only as a discontinuous lamina less than one half an inch thick.

X-ray analyses and thin sections of indurated kunkar show that the predominant constituent is micritic calcite, which has a clouded appearance in thin section. Discrete crystals or grains could not be resolved with

certainty. The lamination, which is sharply defined at low magnifications but poorly outlined under high magnifications, is caused by a pale brown cloudiness, of unidentified origin, localized in thin laminae.

Detrital grains of quartz and accessory calcite, feldspar, biotite, muscovite, ilmenite and hornblende, are found scattered through the micritic matrix in widely varying proportions. In the chalky kunkars, the content of detrital grains exceeds 50%, but in the harder forms, they are far less abundant. Most laminated kunkars contain only 1 or 2% detrital grains. In the laminated kunkar, the detrital grains are commonly concentrated into small pods and laminae, parallel to the lamination of the micrite, in which the grains locally constitute 5 to 20% of the rock, floating in the micritic matrix. Detrital calcite is exceedingly rare in the kunkar, and when found, the interiors of the grains show a complete recrystallization to micritic calcite.

The contacts between most quartz grains and the matrix show small-scale irregularities, which acid-insoluble residues show to be due to etching of the grain surfaces. Most of the sections examined show a few quartz and feldspar grains which have been extensively etched, and in which the grains appeared to have been largely replaced by the micritic matrix. These textural features are shown abundantly in the

PLATE 10.

Solution pipes.

- A. Kunkar layer and solution pipes on the eastern side of a small island due east of Cattle Island. The pole is 5 feet long.
- B. A solution pipe showing a lining of kunkar which is continuous with the surface kunkar layer. $\frac{1}{2}$ mile north-west of Wood's Well.
- C. A solution pipe filled with clayey siliceous sand and containing oriented kunkar pebbles. In a road-cutting near Wood's Well.



underlying weathered sediments, and it is not known how much corrosion has taken place within the kunkar layer itself.

The top of the kunkar unit is generally sharply defined, commonly by the upper surface of a continuous layer of laminated kunkar, up to three inches thick. In most localities, the upper surface of the unit shows undulations and irregularities such as the dome-like projections shown in Plate 9. The cross-sections revealed in cliffs and road cuttings commonly show that the kunkar horizon is interrupted by solution pipes, which extend three or four feet below the top of the kunkar into the underlying parts of the profile, (see Plate 10). The laminated surface layer of the kunkar drapes into the pipes in many cases, and extends partway down the pipe as a marginal lining with decreasing thickness. The pipes are filled with red, clayey siliceous sands. They may contain pebbles of kunkar which are sometimes aligned parallel to the walls of the pipe, (see Plate 10). This suggests that the infilling material has slowly settled into the pipes from overlying parts of the sequence, probably as the pipe developed. The relatively high content of clay-sized material is probably the result of illuviation by waters percolating downwards through the overlying porous sands.

The lower boundary of the kunkar layer is generally

gradational, with soft, chalky kunkar grading down to the underlying pink sand unit. In many sections, the position of the lower boundary is rendered even more indefinite by the presence of veins and rods of calcite, which extend from the kunkar layer into the top foot or so of the pink sand.

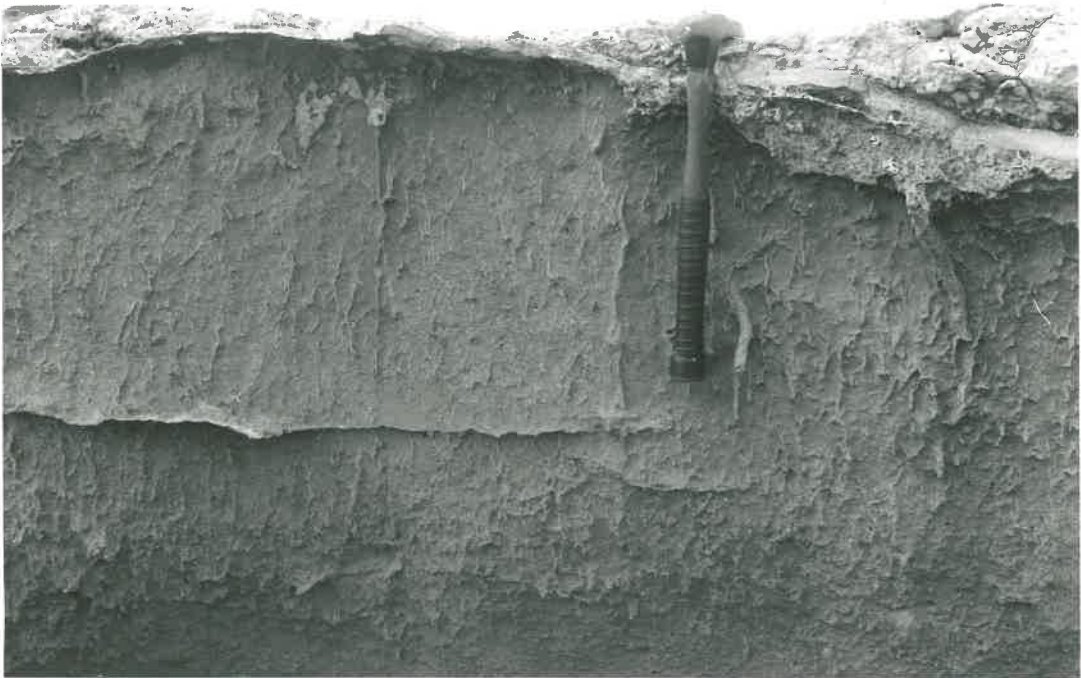
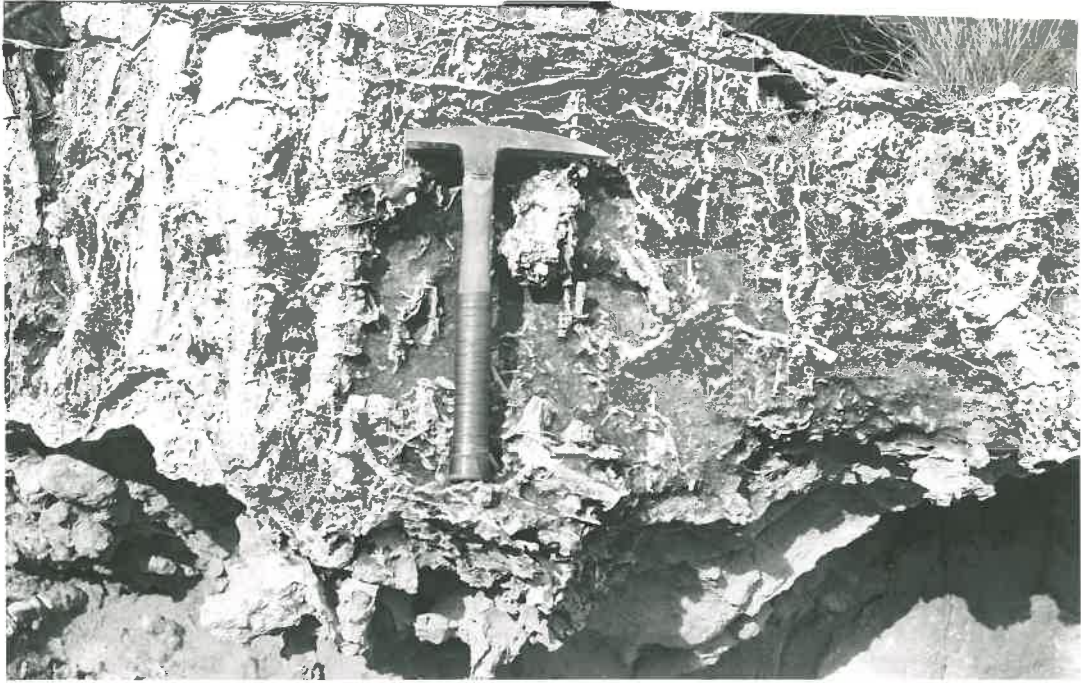
(iii) The Pink Sand Unit.

Underlying the kunkar is a chalky sand, which forms a prominent pink coloured unit in most cliff sections, although in some it is coloured white, or rarely, yellow. The pink sand is generally not indurated, but it possesses a moderate degree of coherence and forms vertical faces in the cliff sections. Towards the top of the unit there is some induration, for it is occasionally quite hard. The thickness of the unit is mostly between one and four feet, but it may be as much as ten feet.

The pink sand shows a bimodal grain size distribution, consisting mainly of a sand-sized fraction and containing a high proportion of clay - sized calcareous material (see Table 3). The sand fraction is mostly quartz, with a grain size distribution and grain properties similar to those of the siliceous sand unit. There is a variable proportion of up to 40% chalky grains of sand size, but the nature of most of these is uncertain. The shape of some indicates that they are probably shell fragments, but many could be

PLATE 11.

Pink sand showing a variety of rod-shaped and laminar segregations of calcite, near Wood's Well.



aggregates of micritic calcite that have formed within the sand. The fine fraction consists of a little silt sized quartz, and calcite. The X-ray patterns of the calcite are sharply defined, show high angle reflections and the d-spacings indicate that there is no replacement of the calcium by magnesium.

In most exposures, the uppermost part of the pink sand unit shows many thin veins and rods of calcite, which extend down from the kunkar layer, (see Plate 11). The veins become thinner as they descend, and eventually disappear. Some sections show a network of rods of indurated to chalky calcite, which are predominantly near-vertical, but sometimes branching, and commonly joined by thin sheets of calcite. These rods are similar in appearance to the rhizcretions in the Recent dune sands, and in some sections appear to be cut by the base of the kunkar, so they may be older than the kunkar. White chalky nodules up to three inches in diameter form a third type of calcite segregation in the pink sand. These segregations are all generally confined to the uppermost one or two feet of the unit, which is relatively coherent.

Below the zone of calcite segregations, the pink sand is homogeneous, and quite soft. Towards its base, recognisable shell fragments become progressively more common and they may outline a vaguely defined stratification. The base of the unit is poorly

defined, with the pink sand grading down to partially weathered aeolianite.

(iv) Partially Weathered Aeolianite.

The soft sands below the pink sands have more of the characteristics of the parent aeolianite than of the weathered material in the overlying parts of the profile, and are considered to be aeolianite which has undergone relatively slight modification. Below the base of the pink sand, the content of shell fragments increases rapidly, and the content of white, chalky calcite decreases. As the content of shell fragments increases, the coarse fragments show a progressive increase in the ordering of their orientation. This is accompanied by a change in the nature of stratification from vaguely defined beds, outlined solely by changes in the content of coarse shell fragments, to sharply defined laminae which are outlined by small changes in grain size and by the orientation of tabular shell fragments. Gradually the partially weathered aeolianite passes down into unaltered aeolianite.

(c) Duplicated Weathering Profiles.

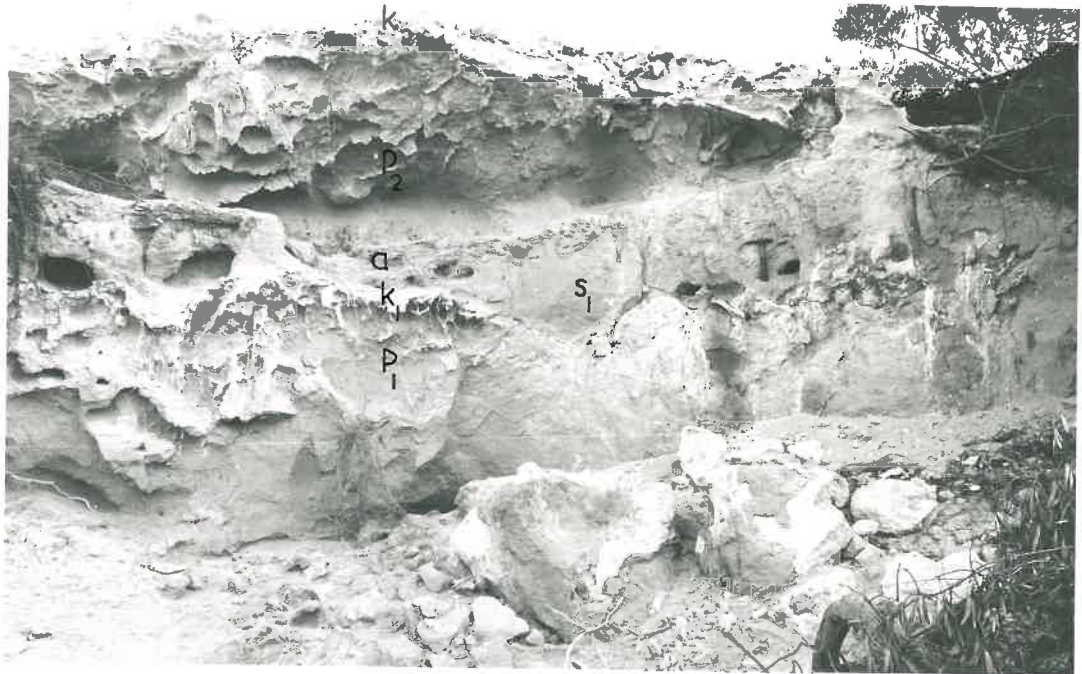
The weathering profiles in many sections are more complicated than the sequence described above, for commonly there are two layers of kunkar present. The upper layer is generally the thicker and in some sections it appears to truncate the lower, or to merge with it in such a manner as

PLATE 12.

Duplicated weathering profiles in the Pleistocene dunes.

A. Salt Creek Point section. Note the two kunkar layers, (k_1 and k_2), each underlain by a pink sand unit (p_1 and p_2). The upper pink sand is underlain by laminated aeolianite (a). This unconformably rests on pockets of the siliceous sand unit (s_1) or on the kunkar of the lower weathering profile. The cliff is about 12 feet high.

B. A buried kunkar layer outlining a dune surface covered by a later aeolian deposit, which is capped by a later-formed kunkar layer. 5 miles south-east of Pelican Point.



to suggest that the upper layer is the younger. The upper layer is underlain by a pink sand unit which may overlies either a siliceous sand unit or the lower kunkar layer. This suggests that there has been a period of erosion between the time of development of the lower weathering profile and the deposition of material in which the upper profile was developed. This is clearly shown in the section exposed in the cliff face along the north-west side of Salt Creek Point, (see Plate 12). In this section, a thin kunkar layer lying above a sequence of pink sand is overlain in low pockets by yellow siliceous sands. Above the yellow sand, and directly above the kunkar surface in higher parts of the undulating layer, rests a thin sequence of laminated aeolianite. This grades upwards into a second pink sand unit, beneath an upper layer of kunkar, which forms the surface. In the cliffs at a point about 5 miles south of Pelican Point, a buried weathering profile distinctly outlines an undulating dune surface beneath many feet of aeolianite, (see Plate 12). The upper aeolianite is capped by a layer of kunkar, which forms part of a second weathering profile of later age than the lower profile.

It is considered that the development of duplicate weathering profiles followed a second period of sand deposition, which led to a new accumulation of calcareous sands above the earlier weathered surface. The younger sands were of varying thickness, so that when they were subsequently weathered, the younger weathering profile

was superimposed on the earlier profile in many places. Duplicated profiles are found along most of the length of the lagoon, but it is not known whether the second period of sand deposition was related to the two phases of dune building which are indicated by the dune topography and the emerged shoreline within the dune range east of the lagoon.

(d) Kunkar-Aeolianite Contacts.

In some outcrops exposed in the near-shore parts of the lagoon, kunkar is found in direct contact with aeolianite which has been little altered by weathering. Although these exposures do not show the typical weathering profile, they afford an opportunity to examine the relationship between the kunkar and underlying material in this section. This gives some information about the mode of development of the kunkar and of stromatolite-like structures found along the lagoon shoreline.

The contact between aeolianite and kunkar is sharply defined, but of irregular outline, and vein-like projections of kunkar may extend several centimetres into the aeolianite. The aeolianite consists of quartz and about 25% well rounded calcareous shell fragments, cemented by interstitial sparry calcite, with the detrital grains in grain-to-grain contact. The kunkar consists predominantly of micritic calcite, and generally contains only 1 or 2% floating quartz grains, with practically no detrital calcareous grains.

In the aeolianite, both calcareous grains and cement show partial replacement by cloudy micrite, and the

replacement becomes more widespread within a few centimetres of the kunkar contact. It is thought that this conversion to micrite is achieved by recrystallisation of the original calcareous components. The initial stage of replacement is the development of small cloudy patches of micrite within unaltered shell fragments or clear sparry cement. The replaced patches enlarge and coalesce, and eventually spread over complete grains and patches of cement. Recrystallisation has been intense in some patches within the aeolianite, and has completely destroyed the distinction between grains and cement, forming a uniform micritic matrix between detrital quartz grains.

At the kunkar-aeolianite contact, the boundaries of some calcareous grains have merged with the kunkar. A few large shell fragments were observed to extend across the boundary deep into the kunkar. The marginal zones of the ends immersed in the kunkar have completely merged with the micrite of the kunkar, and only remnants of the internal organic structure along the axes of the grains have been left to indicate the former extent of the fragments.

Recrystallisation destroys the distinction between calcareous grains and cement, thus producing a uniform matrix of micritic calcite. The process commences within the aeolianite, and it is possible that some of the smaller veins of kunkar have been formed entirely by recrystallisation of patches of detrital calcareous grains and cement. In the larger veins and the main bodies of kunkar, recrystallisation

explains the absence of detrital calcareous grains, but it does not account for the low content of detrital quartz grains or the presence of much of the calcite.

Quartz grains on both sides of the aeolianite-kunkar contact show etched surfaces, and there is no pronounced increase in the extent of etching at the contact or within the kunkar layer. It is considered, therefore, that corrosion plays no great part in the removal of quartz grains from the site occupied by the kunkar.

The veins of kunkar within the aeolianite are commonly very irregular in outline, and enclose, either partly or completely, small lenses and pockets containing an abundance of detrital grains. The shape of the veins is commonly so irregular that it is very unlikely that they were formed by the infilling of open fissures. They suggest that crystallisation of the micrite has forced the aeolianite apart, and has detached small groups of detrital grains away from the main rock mass. Within many of the detached and semi-detached groups, it appears that the detrital grains within the groups have been forced apart, for the grains become more widely separated than in the unaltered aeolianite, and in some groups, most of the grains are so widely separated that they could not be in grain-to-grain contact.

Further evidence indicating that disruptive forces are generated by the development of the kunkar is shown in a few localities where laminae containing an abundance of tabular shell fragments are cut by kunkar. Within a few

PLATE 13.

Stromatolite-like masses of laminated calcite.

A. Columnar masses near the mouth of Salt Creek.

B. A single column lined by indurated aeolianite
at Trevarrow's point.



millimetres of the contact, the orientation of the grains is disturbed, and individual grains may be rotated by as much as 90° . In one thin-section, a lamina of aligned grains was seen to be cut by a vein of kunkar, and as the lamina approaches the contact, the alignment of the grains is gradually deflected so that the alignment approaches the direction of the vein.

These kunkar-aeolianite contacts show two major points. The first is that the calcareous components of the aeolianite are recrystallised and converted to micritic calcite. This micrite is supplemented by additional calcite in certain clearly defined sites, and a layer or a vein of kunkar develops. The second point is that the kunkar layers can grow by expansion within the aeolianite, and the expanding layers force most detrital grains out of the sites of micrite deposition. Below the kunkar surface, the effects of the expelling forces are limited to a narrow zone, and it is thought that the main growth of the larger masses of kunkar take place on the upper surfaces of the layers, so that the layers expand upwards.

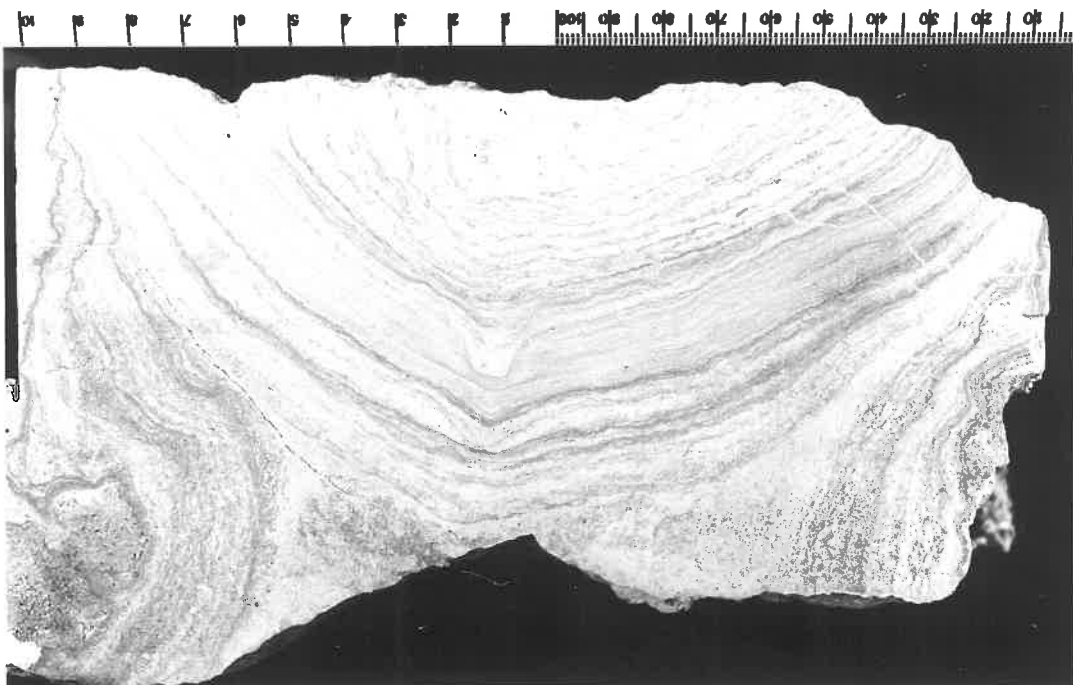
(e) Stromatolite-like Bodies.

In the shallow water areas of the lagoon south of Magrath Flat, laminated masses of micritic calcite form extensive sheets and isolated structures projecting above the lagoon-floor. Many of the isolated structures are dishshaped, clubshaped or cylindrical, and are similar to some organic stromatolites. Cross-sections of these

PLATE 14.

Dish-shaped laminated masses of calcite.

- A. Laminated masses within the kunkar layer at Trevarrow's Point. Scale is 12 in. long.
- B. A cross-section of a laminated mass, showing the main part of the laminated mass resting above a sand-filled pipe, outlined by laminated kunkar. From Trevarrow's Point. The scale is in mm. and cm.



bodies show dish and coneshaped arrangements of finely crenulated laminae, which are concave downwards (see Plate 14).

Although these masses may be surrounded or covered by algal mats, it is considered that the algae have played no role in the formation of the laminated structures. The algal mats are composed of algal fibres, derived from the deeper parts of the lagoon, which have been concentrated along the shoreline at times of strong winds. They are commonly left stranded at times of normal water level, and eventually dry out. They trap very little detrital material, and appear to have no ability to bind trapped sediment to the underlying sand or rock. The fibres do not adhere to the laminated masses, nor are there any traces of algal fibres in the latter.

In thin section, the laminated material is identical with laminated kunkar. X-ray analyses show that the fine matrix is calcite which contains no magnesium, whereas the lagoonal muds contain calcite which generally has a significant magnesium content.

These laminated masses are always associated with an eroded kunkar layer extending from the shoreline out into the lagoon. Unfilled cylindrical bodies similar to solution pipes are commonly found with the solid bodies and the laminated sheets. In texture and composition the laminated masses are identical with the laminated kunkars described earlier. They show no internal evidence to

relate the fine calcite with the muds of the lagoon, or to support an algal origin. It is concluded that these laminated sheets and isolated structures along the shores of the lagoon are a form of kunkar.

It is considered that the isolated structures are masses of kunkar which have been rendered resistant to erosion by a deep zone of cementation by micrite, so that when adjacent kunkar was undermined by the removal of underlying sandstone or sands, these structures were left isolated.

The method by which the laminated micrite was localized in the form of the cone- and dish-shaped structures is not known. They are rarely found away from the lagoon, but this may reflect the greater degree of erosion and exposure of the kunkar along the lagoon. It is thought that the structures were formed by the deposition of micrite within solution pipes, perhaps by the infilling of solution pipes in an earlier formed kunkar horizon during the development of a later kunkar layer.

(f) Development of the Kunkar.

The kunkar layer within the aeolianite is a horizon which is enriched in calcium carbonate, in the form of micritic calcite. The nature of the weathering profile suggests that the main source of the calcite has been from the overlying sands, which are now largely leached of calcareous material. The calcite was probably transported downwards in solution and by illuviation during wet seasons,

leaving a leached siliceous sand above. The gentle undulations of the kunkar layer suggest that this downward movement was arrested near the top of the ground water table, and the calcareous material redeposited as micritic calcite. The conversion of sparry calcite cement and detrital calcareous grains to micrite within the aeolianite suggests that the pink sand unit is a weathered aeolianite in which the calcareous components have been converted to micrite, but not redistributed to any great extent. It is likely that the pink sand was largely located below the ground water table, so that it was not subjected to effective leaching by downward percolating waters. The development of the kunkar layer would largely protect the pink sand from leaching subsequent to any fall in the level of the ground water table.

The processes which led to the organization of the calcite in its present form within the zone of calcium carbonate enrichment are not fully known. It appears that deposition of the calcite took place within well defined layers, from which detrital grains were progressively expelled. The most feasible manner in which this could take place would be by accretion of calcite on the uppermost surface of the layer, with the micrite pushing detrital grains upwards as it was deposited. The regular arrangement of laminations suggests that this type of accretion has taken place. There may have been some growth within the micrite layers, for some detached groups of detrital grains

suggest that the grains have been separated within the group.

The development of solution pipes is thought to have resulted from downward movement of waters capable of dissolving the calcareous constituents of the underlying kunkar and pink sands. They are most likely to have formed after a fall in the level of the ground water table, for this would allow waters percolating down through the leached siliceous sand unit to pass through and to enlarge cracks in the kunkar, thus developing well-defined channelways. As the calcite below the channelways was removed, the overlying siliceous sands and remnant blocks of kunkar settled into the pipes.

The laminated layer of kunkar around the margins of the pipes, which is often continuous with the surrounding kunkar sheet, shows that lime-bearing solutions were actively depositing calcite some time after the formation of the pipes. The laminated lining may have been formed by periodic deposition of calcite derived from evaporating interstitial waters at times when evaporation was confined to the contact with the siliceous sand unit. It is likely that the siliceous sand unit would become relatively dry during dry seasons, because its low clay content would lead to a high permeability. The chalky and indurated kunkar would have a lower permeability and could be expected to retain interstitial waters for longer periods. Interstitial water escaping from these two units would abruptly meet a relatively dry sand and evaporate. Over a considerable portion of the

dry season this evaporation would be localised at the base of the siliceous sand, causing a layer of calcite to accumulate. A similar process probably operates at the top of the kunkar layer, for the lining of the solution pipe and the main kunkar layer are continuous in many cases.

SUMMARY.

The Coorong Lagoon occupies the northern portion of a long interdunal depression between a Recent dune range and a compound range of Pleistocene dunes. Within portion of the lagoon, eroded remnants of the Pleistocene dunes extend westwards to the edge of the Recent dunes, indicating that part of the present interdunal depression is superimposed on an older dune-covered land surface.

Calcareous sands of both the Recent and the Pleistocene dunes have been subjected to post-depositional alteration. These changes have only slightly modified the Recent dunes, and have not influenced the type of detritus which is derived from them by the lagoon. The Pleistocene dunes have been more extensively altered and they show a well developed weathering profile. This includes an indurated kunkar layer, which is resistant to erosion and has thus influenced both erosional and depositional processes within the lagoon. Weathering of the Pleistocene aeolianites has produced a cover of loose siliceous sands on the dune surfaces. Much of this sand was probably present in the area now inundated by the lagoon and formed a ready source of easily reworked detritus.

THE COORONG LAGOON

MORPHOLOGY.

In this section the general morphological features of the Coorong Lagoon are discussed. A more detailed account of these features will be presented in subsequent sections discussing the sediments and the depositional environments of the different parts of the lagoon.

1. LAGOON MARGINS.

The lagoon occupies the greater part of an interdunal depression between low kunkarized dunes of the eastern mainland, and Recent unconsolidated dunes of Youngusband Peninsula. In some places, the lagoon is separated from these marginal confines by low-lying sand and mud flats, now located above the normal reach of the lagoonal waters and covered by plant growth.

Much of the eastern shoreline consists of low cliffs and steep slopes rising to about 50 feet or less above the lagoon level, with a narrow beach of sands and shell accumulations marking the high water strandline. In a few localities, low dunes up to about 20 feet high have been constructed from lagoonal sediments along the eastern shoreline.

Most of the western shoreline is bordered by the Recent unconsolidated dunes of Youngusband Peninsula. In part they are fixed by a cover of vegetation, but large portions consist of sand drifts moving north-eastwards into the lagoon. Along parts of the western shoreline in the

in the southern half of the lagoon, a disconnected series of kunkarized Pleistocene dune outcrops separates the lagoon from the Recent dunes.

Both extremities of the lagoon are gradational. At the northern end, the lagoon joins a channel which forms one of the outlets of Lake Alexandrina at Pelican Point. This channel extends northwards to the mouth of the River Murray and thus connects the Coorong to the Southern Ocean. This connection is the only route by which sea water can enter the lagoon, as everywhere else the dune system of Youngusband Peninsula forms a complete barrier at all times.

At its southern end the lagoon becomes very shallow, and over a length of about seven miles it is only periodically inundated. Mud flats, slightly above the level of the lagoon floor, and covered by Samphire and other low plant growth, confine the southward spread of the lagoon waters in normal seasons to a point about 10 miles south of Salt Creek Point. This locality is taken as the southern end of the lagoon. Further to the south, stretches a continuation of the interdunal depression, occupied by a chain of playa-like lakes which are surrounded by low lying mud flats, covered by low plant growth. At times of exceptionally high water level, the lagoon extends southwards into the northern parts of the lake area, but this event took place only once in the course of the present investigation.

Midway along its length, westward projections of the kunkarized dunes of the mainland and a few islands narrow the lagoon considerably. The constricted section is about $7\frac{1}{2}$ miles long, and over much of its length the lagoon is very shallow. The constricted area separates the lagoon into two divisions, and has led to the development of marked differences in the nature of the waters and the sediments in these divisions. In this investigation, the two divisions have been termed "The Northern Lagoon" and "The Southern Lagoon", and the constricted connection has been called "The Hell's Gate Passage". Each of these divisions will be discussed in later sections.

2. THE TOPOGRAPHY OF THE LAGOON FLOOR.

There are no published charts or topographic maps of the Coorong. Systematic mapping of the lagoon floor was confined to the Southern Lagoon during the course of the current investigation. The map, Fig. 16, was compiled from soundings made with a graduated pole, taken along traverse lines between points located by compass bearings and on aerial photographs. Scattered recordings and observations in the Northern Lagoon were gathered during the collection of water and sediment samples.

Along most of its eastern side, the floor of the lagoon slopes very gently to the west and forms a nearly flat lying platform, the width of which varies and ranges up to 4,000 feet. The surface of most of the platform lies close to

the low water level, and a large part of it lies slightly above that level, so that extensive areas are exposed continuously throughout the summer months. The outermost parts of the platform may be as much as 5 feet below the low water level. In most localities, the platform is terminated by a steep slope at its outer edge, where the lagoon floor drops suddenly through a depth of a few feet.

Beyond the marginal slope of the eastern platform, the lagoon floor forms a depressed area occupying the central part of the lagoon. The floor of the depression is smooth and flat or very gently sloping. The width of the central depression varies, but it generally occupies more than one half of the width of the lagoon. In a few localities it is greatly constricted by extensions of the shallow marginal platforms, but it maintains its continuity, except at Salt Creek Point, near the southern end, and in the Hell's Gate Passage. The central depression is generally less sharply defined along its western side. The lagoon floor gradually slopes up to the shoreline at varying angles, and gradually flattens to form a western platform area covered by shallow water.

The shallow areas of the western side of the lagoon are of two types. One consists of a platform similar to that of the eastern side, with outcrops of kunkar showing that an eroded dune topography forms the framework of the platform. The second type may also show extensive, flat lying areas, but these are entirely depositional structures which have

been formed by the redistribution of sands derived from the Recent dunes. A steep slip face is found at the outer edge of some of these deposits. In order to distinguish these two topographic features in this text, the term "platform" has been used to designate the flat lying areas which show evidence of an erosional framework, and the term "shelf" has been used to designate the flat areas of purely depositional origin.

Parts of the channel through the Hell's Gate Passage are up to ten feet deep at times of low water level, and the eastern sides of these deep sections are partly formed by near vertical faces cut in the aeolianite of the adjacent dunes. The channels in the constricted sections of the central depression of the Southern Lagoon are very narrow and deep, and confined by steeply sloping sides. Although these narrow channels may have been formed entirely by current action in the lagoon, it is considered to be more likely that they were excavated by Salt Creek at a time when sea level was lower than at present. Along its present course the creek spreads into wide swamps and lakes in the interdunal depressions, and the overflow from these has cut a well defined course in the form of a narrow valley across the Pleistocene dunes in such localities as the area upstream from the present mouth. Prior to the inundation which produced the lagoon, the creek probably flowed into the low-lying interdunal depression between the Pleistocene dunes of the mainland and those along the eastern side of

Younghusband Peninsula, and cut a way across areas of higher ground which segmented this depression. After the inundation of this low-lying area during Recent times, the lagoon has drowned this part of the creek's course. Water movements within the lagoon have maintained the stream-cut channels through the barriers which segmented the interdunal depression.

HYDROLOGY.

The investigations of Alderman and Skinner (1957), Skinner (1963), and von der Borch (1962 and in press) showed that the waters of the Coorong Lagoon have an ionic composition very close to that of normal sea water. During the current investigation, an examination was made of the seasonal and spatial variations in the salinity of the lagoon waters, mainly in the Southern Lagoon. Although the composition of the salt content of the lagoon waters is very similar to that of normal sea water, at least one ion, calcium, shows a slight, systematic variation with increasing concentration. It was therefore decided to use chlorosity, rather than salinity, as the main parameter in following the variations in composition of the waters.

1. WATER LEVEL VARIATIONS.

Along most of its length, the lagoon shows no perceptible tidal changes in water level. Near Pelican Point, at the northern end, the water level was observed to fall a few inches in about three hours on a calm day, and it is very likely that there is a moderate degree of tidal variation in this area. But along the remainder of the lagoon, observed changes in water level were related to wind activity or to seasonal changes. Changes of a few inches in the water level can be caused by winds blowing along the length of the lagoon. At the southern end of the lagoon these effects are amplified, and even moderate winds may lead to

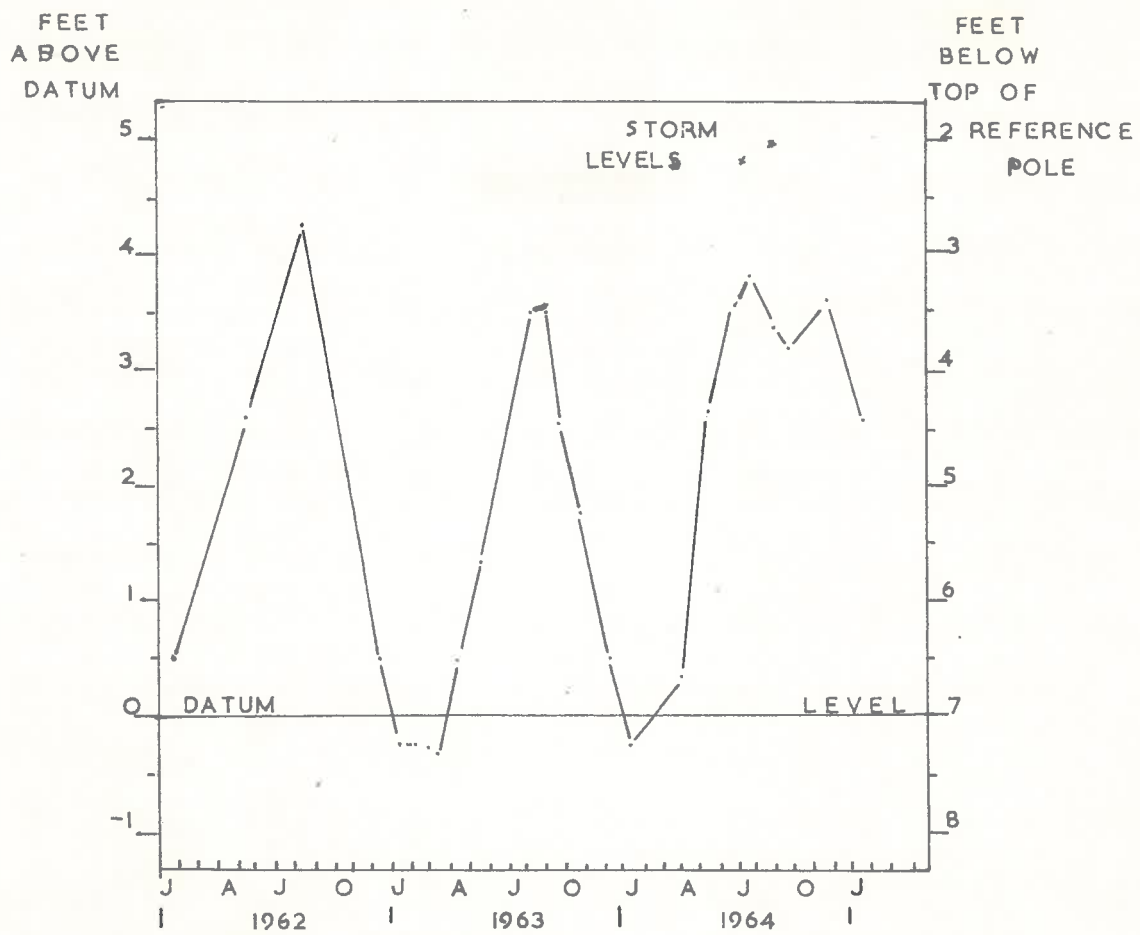


FIGURE 3.

WATER LEVEL VARIATIONS IN THE COORONG LAGOON.

variations of about two feet in a few hours. An investigation of water level oscillations, with particular reference to the development of seiches, is being carried out by members of the Department of Mathematics in the University of Adelaide.

The lagoon water level shows an annual oscillation with an amplitude of about four feet (see Fig. 3). The lowest point is reached towards the end of summer. During autumn the water level rises, slowly at first, but later more rapidly. During winter, the water level is normally about 4 feet above the low level of summer, but during storms it may rise a further 1 or 2 feet, and then drops as the weather abates. Late in the winter the water level falls, and a fairly rapid decline continues during the spring months, until the low level of summer is reached.

During the greater part of the year, the rate of flow in the River Murray is relatively low. A system of barrages has been constructed north from Pelican Point and at localities further upstream to maintain a stable water level. At such times, the river has little or no influence on the Coorong Lagoon. The river flows strongly after winter rains in the catchment area, and in some years is subjected to floods. These strong flows generally arrive in the lower reaches after the commencement of the annual rise in lagoon water level, and even after the lagoon has attained its highest level. Before the river floods, the barrages are opened to varying degrees, depending on the

expected rate of flow, and this slightly modifies the effects of a strong flow on the lagoon. Basically the effects of the river on the lagoon have not been greatly altered by the construction of the barrages, for the timing of the strong flow is only slightly altered.

The lagoon may fill before the strong river flow reaches the river mouth, so the river is not the principal cause of the annual rise in water level. The river can modify the annual oscillation, particularly at times of large floods. A great flood in 1956 led to an exceptionally high water level in the lagoon, and this high level was maintained during part of the summer of 1956-57. Late in 1964, a moderate flood peak reached the mouth of the river after the lagoon level had begun to drop. This caused the water level to rise again, and the level remained high well into the summer of 1964-65, (see Fig. 3).

It is unlikely that evaporation is the main cause of the annual decline in water level, although it may be a major contributor to the later stages of the decline. Much of the decline takes place in the relatively cool spring months, before the lagoon waters show a great increase in salinity.

Thus the main cause of the annual oscillation in water level is to be found outside the lagoon. The water compositions discussed in following pages show that much of the inflowing water is sea water. Although the mechanism of the cause is not known, it appears that seasonal

TEMPERATURE
°C

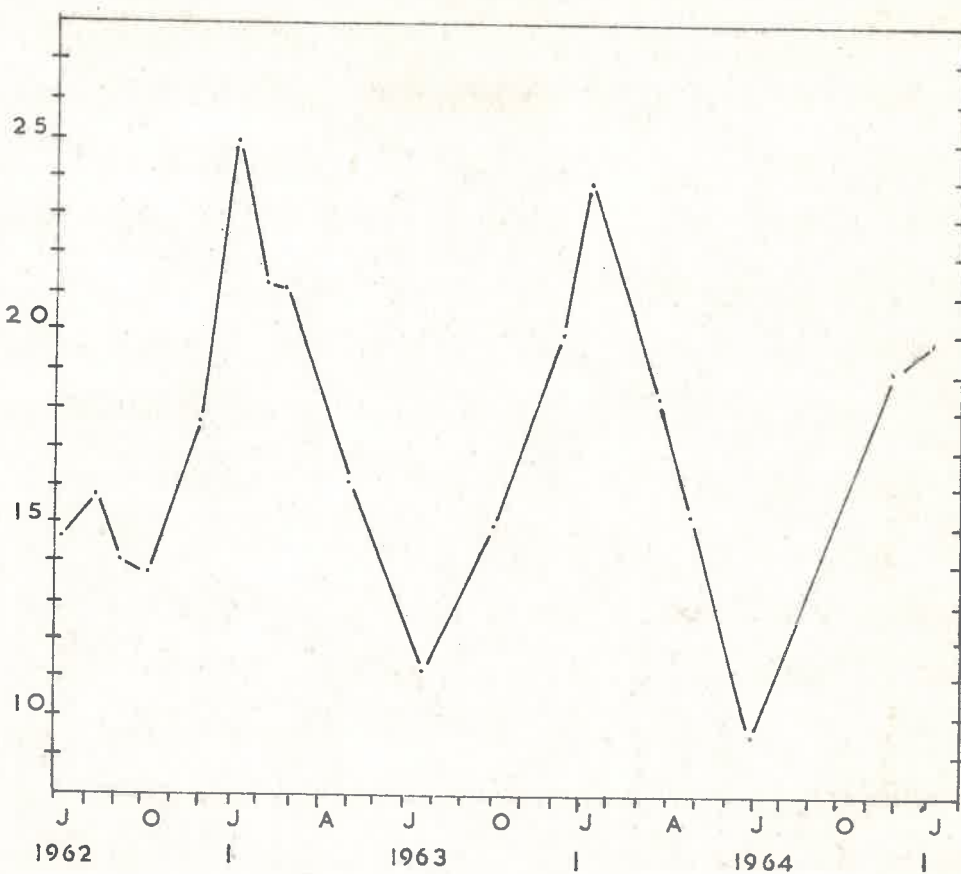


FIGURE 4.

SEASONAL VARIATION IN THE AVERAGE TEMPERATURE
OF LAGOON WATERS.

variations in the waters of Encounter Bay, outside the mouth of the River Murray, cause the build up and the decline in lagoon water level.

2. TEMPERATURE.

The waters of the lagoon show a fairly uniform distribution of temperature during the cooler months of late autumn to early spring. There may be a small variation during the day, and on warm, sunny days the temperature rises by nearly 1° C. Differences between surface and bottom temperatures are generally confined to early morning, when the surface temperature may be 0.5° C lower than the bottom temperature.

During the warmer months of the year, shallow waters may be more than 5° C warmer than adjoining surface waters in deeper areas. There is commonly a difference between surface and bottom temperatures. Early in the morning the surface waters may be 0.5° C cooler than the bottom waters, but during the day this difference is reversed, and surface temperatures are often 1 or 2° C higher than bottom temperatures. As the day progresses both surface and bottom temperatures rise by 2° C to 4° C.

There is a marked seasonal variation of water temperature, reflecting the change in air temperatures. Average winter temperatures observed were between 9° C and 14° C, while those of summer were between 20° C and 25° C, (see Fig. 4).

3. pH.

The pH of lagoon waters was mainly in the range 8.25 to 8.50, (see Fig. 5), which is slightly in excess of the range 8.1 to 8.3 given by Svedrup and others (1942) for sea water in equilibrium with the atmosphere. This excess may be due to the extensive growth of filamentous algae and aquatic plants in the lagoon. Exceptionally high values between 8.6 and 9.2 were obtained from water within concentrations of algal debris at the shoreline.

There was no systematic difference between the pH of surface and bottom waters, and these two values were commonly in close agreement. No regular pattern was observed in the areal distribution of pH values. It took three or four days to collect a set of water samples and the variations shown were probably due to the interaction of a number of variables, including locality, time of the day and temperature. The only systematic variation of pH with time was noted in the Bul Bul Basin, where a lowering of the pH was noted during the low water period of 1963, (see Fig. 5). This was at a time when the basin was almost separated from the remainder of the lagoon, and it is likely that very high temperatures (25° C) and the very high salinity (chlorosity = about 50‰) had greatly inhibited the growth of aquatic plants which are normally quite prolific in the basin.

4. CHLORIDE ION CONTENT.(a) Variation with depth.

Chloride ion concentrations of surface and bottom waters at any one locality were often in close agreement, differing by less than 1%. This indicates good vertical mixing of the waters at most times. However differences of 1% or 2% are common, and even larger differences were observed on a number of occasions. These differences appear to be related to widespread movements of surface water. They were generally recorded at times when water of low salinity was moving into the lagoon at the northern end, causing displacement of the surface waters over a wide area.

Samples collected from near Stony Well Island in May 1963, (see Fig. 15) showed water with a chlorosity near that of sea water moving southward above hypersaline waters. The surface waters showed a chlorosity about 30% lower, and a temperature about 1° C lower, than did the bottom waters. This flow probably marked the beginning of the seasonal rise in water level for that year. Later in the winter of the same year, there was a pocket of water in the deep area north of Salt Creek Point which showed unusually high chlorosity, (see Fig. 15). Chlorosity values of the bottom water, then about 14 feet below the surface, were about 8% higher than those of the surface water. This indicates that in this deep part of the lagoon vertical mixing of waters may be relatively slow. Other differences in the chlorosities of surface and bottom waters are shown in Fig. 15 .

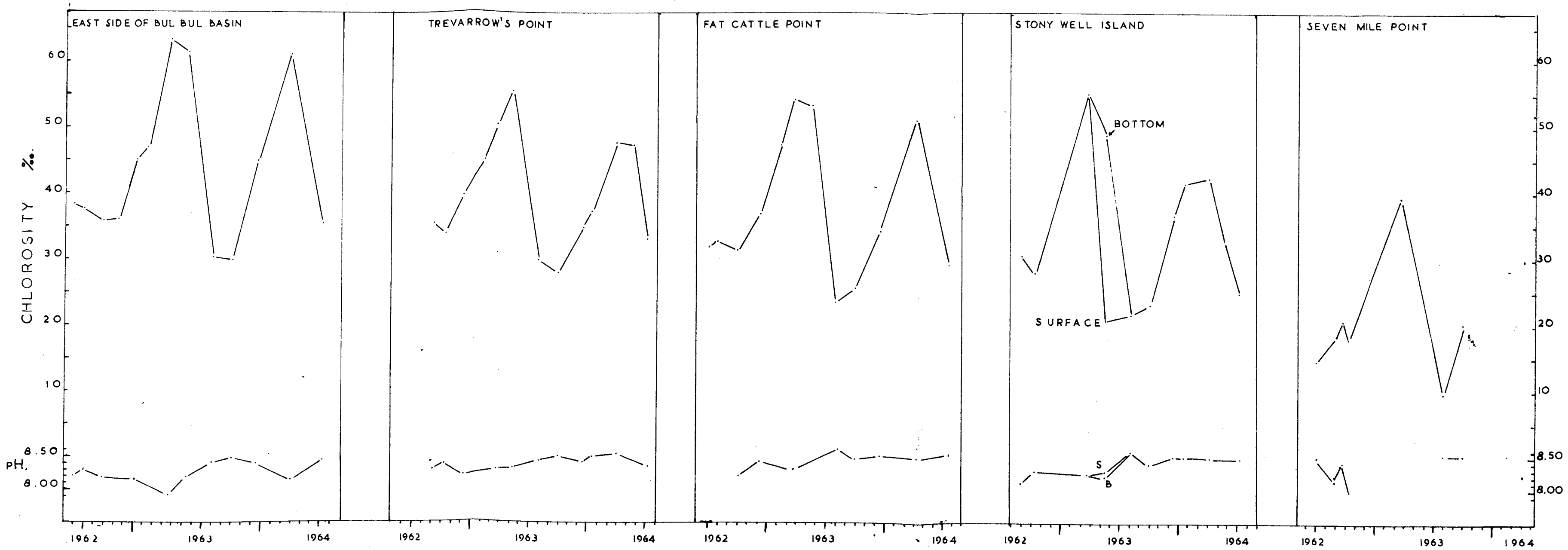


FIGURE 5

VARIATIONS IN CHLOROSITY AND PH AT 5 SELECTED LOCALITIES.

(b) Regional and seasonal variations.

The lagoon waters show a marked salinity gradient throughout the year, but the direction and the intensity of the gradient shows a seasonal variation. At times of relatively little water movement, samples taken along cross sections of the lagoon show closely agreeing chlorosity values, and isochlor lines are approximately normal to the long axis of the lagoon. Isochlors which are strongly inclined to the axis of the lagoon are shown in some areas at certain times (see Fig. 15). In many cases these displacements are accompanied by differences in the chlorosity of surface and bottom waters, and it is considered that they indicate movement of the surface waters, mainly under the influence of wind.

The distribution patterns of winter months (see Fig. 15) show a progressive increase in chlorosity between Pelican Point and the southern end of the lagoon. The Northern Lagoon shows varying degrees of influence by the River Murray, and either brackish or marine waters may be found in this section. The Southern Lagoon is entirely hypersaline, and shows an increase in chlorosity from about 23‰ at Mack Point to about 30‰ at Salt Creek Point, and there may be a slight increase in the area further to the south.

During spring months, the water in the Northern Lagoon shows an increase in concentration to normal marine compositions. One of the causes of this is the outflow of slightly hypersaline waters from the Southern Lagoon during

the spring. In the Southern Lagoon, the chlorosity is similar to that of the winter. In the area near Salt Creek Point, the chlorosity may drop slightly, as mixing of waters along the length of the lagoon continues so long as the water level is relatively high.

Late in the spring and during the summer, evaporation leads to an increase in salinity throughout the lagoon. At the same time, because the water level is low, the lagoon is divided into three largely independent parts, tenuously connected by shallow stretches of water. In the Northern Lagoon, there is a large southward increase in salinity. At the northern end, the chlorosity is close to that of sea water, except when the barrages have been opened (see Fig. 15). At such times, brackish waters are produced as the fresh water moves into the lagoon and mixes with lagoon waters. As the flow of river water is generally low in the summer, brackish conditions are less common than marine conditions in this part of the Northern Lagoon. In the southern half of the Northern Lagoon, hypersaline conditions are found throughout the summer. The chlorosity reaches about 40‰ near Needles Island, and progressively decreases to the north.

The water of the Southern Lagoon is more highly concentrated during this period, and there is a difference of between 15 and 20‰ in the chlorosity values shown immediately to the north and the south of the Hell's Gate Passage. This indicates that the shallow areas in the

passage prevent significant exchange between the two major divisions of the lagoon while the water level is low. Because of this separation from the open end of the lagoon, the Southern Lagoon shows higher salinities than the Northern Lagoon. A salinity gradient develops in the direction opposite to that shown in winter. The waters show a southward decrease in chlorosity of about 5‰ between Hack Point and Salt Creek Point, reflecting the southward increase in the water depth from about 4 feet to about 10 feet. In the shallower northern areas, evaporation produces a higher rate of increase in salt concentration than in the deeper southern areas. The comparative narrowness of the lagoon and the presence of constricted sections at Cattle Island, Pelican Island and Wataleera Bay prevent ready longitudinal circulation of the waters, and allows the concentration difference to build up during the period of low water level.

The water in Bul Bul Basin is only about 3 feet deep at this time and evaporation leads to a faster rate of increase in salinity than in the adjoining Salt Creek Basin. The sand bar across the lagoon at Salt Creek Point prevents ready exchange of water between the two basins, and at times the connection may be completely severed. A large difference in salinity develops as the summer progresses, and water in Bul Bul Basin reaches chlorosity values which are about 15‰ higher than those in the Salt Creek Basin.

At the southern end of the lagoon, the Ephemeral Lagoon becomes completely dry during the early summer. Its water

drains to the north as the water level drops, and most is gone before high salinities can develop. As the water level falls, some isolated patches of water are left in the emerged areas exposed along the margins of the lagoon. These are mostly of small extent, and the water soaks into the drying sands before they begin to precipitate halite. Two larger bodies of water are annually left isolated near Trevarrow's Point. One is in the large inlet to the north of the point, the other is on the platform area to the east of the point. Each of these retains large, shallow sheets of water, which may persist for most of the summer. They attain high salinities and eventually precipitate halite. The halite deposits are dissolved again during the following period of high water level, and extensive circulation of water prevents any tendency for the redissolved salt to remain in the areas.

During the autumn, the water level rises throughout the lagoon and there is an influx of less saline waters into the areas of hypersaline conditions. The incoming water is of marine composition at first, but may later be brackish. The rise in water level overcomes the two major barriers to water movement, and the lagoon again behaves as a single elongated body of water. Dilution of the waters at the northern end of the Southern Lagoon leads to the reversal of the summer salinity gradient (see Fig 45) and the rise in level produces uniform compositions across the bar at Salt Creek Point. As the higher water level enables better

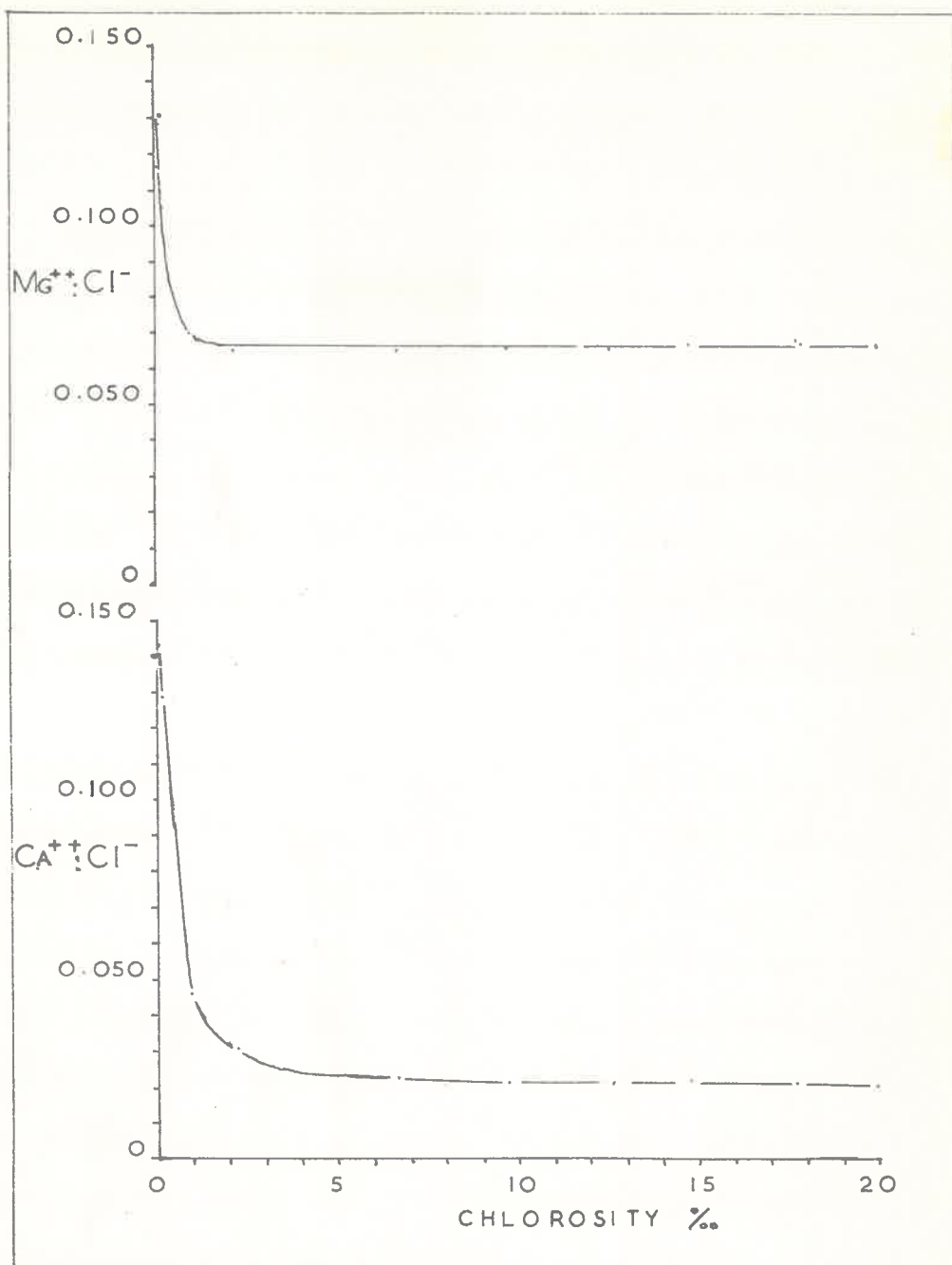


Figure 6.

The magnesium and calcium content of brackish water
in the Coorong Lagoon.

longitudinal circulation along the length of the lagoon, the summer distribution pattern is destroyed and the distribution pattern of winter months begins to develop.

5. CALCIUM, MAGNESIUM AND SULPHATE ION CONCENTRATION.

The concentrations of these ions show a wide seasonal variation which follows that shown by the chloride ion over the range of concentrations shown by the main mass of lagoon water. However, in greatly diluted waters the river waters influence the relative concentrations of these ions, while at high concentrations the calcium and sulphate ions do not show increases strictly proportional to those of the chloride ion.

In brackish waters of very low concentrations, the $\text{Ca}^{++} : \text{Cl}^-$ ratio is in excess of that in normal sea water, reflecting the higher ratio found in River Murray waters, (see Fig. 6). Above a chlorosity of about 6‰, the $\text{Ca}^{++} : \text{Cl}^-$ ratio approaches that of normal sea water, as the salt content of the river water is very low. Thus, in most brackish water in the lagoon, all but a very small proportion of the calcium has been derived from sea water.

In lagoon waters showing a chlorosity close to that of sea water, the calcium content is the same as that of sea water. As the chlorosity rises into the hypersaline range, the calcium content shows a linear increase, but the rate of increase is lower than that of the chlorosity, and the $\text{Ca}^{++} : \text{Cl}^-$ ratio steadily decreases, (see Fig. 7). Thus,

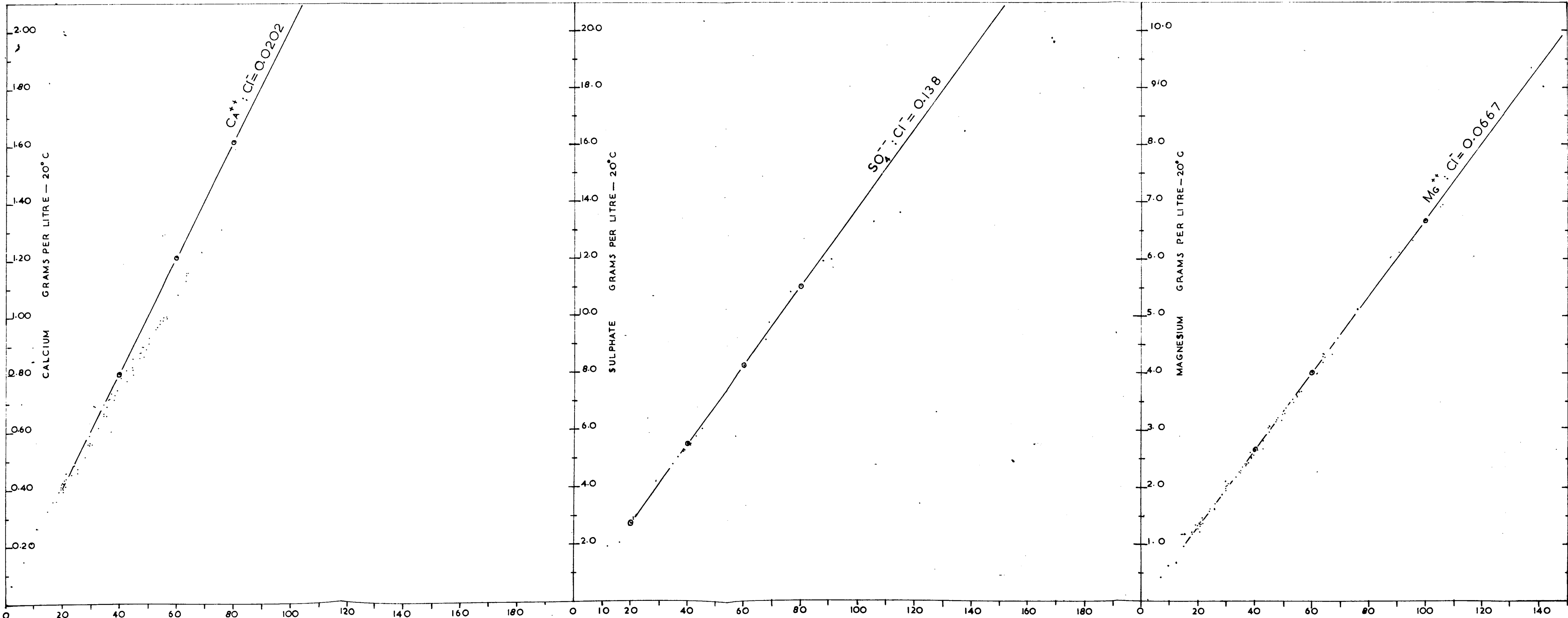


FIGURE 7

CONCENTRATION OF Ca^{++} , SO_4^{--} AND Mg^{++} IONS VS. CHLOROSITY.

CHLOROSITY %.

as the lagoon waters evaporate, calcium is continually being removed from solution, and is probably being deposited as calcium carbonate.

In small isolated bodies of lagoon water, the salinity rises much higher than in the main mass of lagoon waters. The linear increase in calcium content continues up to chlorosity about 90‰, above which the rate of increase falls, and above chlorosities of about 100 ‰, the calcium content decreases rapidly as the chlorosity rises, see Fig. 7.

At normal marine chlorosities, the $\text{SO}_4^{2-} : \text{Cl}^-$ ratio is the same as that of sea water. The concentration of sulphate ion rises at the same rate as the chlorosity over the range of concentrations found in the main body of lagoon water. Above a chlorosity of about 90‰ the rate of increase falls over a short interval, (see Fig. 7). This suggests that the sudden decrease in calcium content at about the same chlorosity is due to the deposition of gypsum. The chlorosity of the main body of lagoon water does not rise sufficiently high during summer to induce the deposition of gypsum, so the loss of calcium from the evaporating waters there is more likely to be the result of deposition of calcium carbonate.

The magnesium content of brackish water shows a similar pattern to that of calcium (see Fig. 6), reflecting the high $\text{Mg}^{++} : \text{Cl}^-$ ratio of river waters. In lagoon waters with a chlorosity close to that of sea water, the concentration of magnesium is similar to that of sea water. As the chlorosity

rises, the concentration of magnesium rises at the same rate as the chlorosity, (see Fig. 7), over the range of concentration found in the main body of lagoon water.

6. THE SOURCE OF LAGOON WATER.

There are five possible sources from which the lagoon water could have been derived. These are:-

- (a) Seeps along the shores of the lagoon:
- (b) Rainfall over the lagoon, and rain water run-off from the adjacent areas:
- (c) Salt Creek:
- (d) The River Murray:
- (e) The ocean, via the mouth of the river.

Water runs into the lagoon continuously from many seeps along the western side of the lagoon, and along the eastern side after winter rains. The rate of flow is very small, and no perceptible lowering of salinity has been detected near the known seeps.

Rain fall over the lagoon is slightly less than 20 inches per annum. Most of this falls during the winter months, so a significant proportion of the dilution of the lagoon waters must be due to rain water. Surface run-off from the Pleistocene dunes is very low. Over larger tracts of exposed kunkar, small streams form while the rain is falling, but they run only as far as low lying areas near the lagoon shoreline, where the water soaks into the sand, or forms small swampy lakes. Rain water runs off the mud

flats at the southern end of the lagoon, but the main flow is commonly at times of high water level and strong wind agitation, and no dilution of lagoon waters has been detected. The catchment area for this flow is small, and it is considered that the quantity of water which enters the lagoon this way is insignificant.

Salt Creek has not run since 1948, and local residents say that this flow was the first for 7 years. The flow of water through Salt Creek before the construction of drains in the South East district near Kingston and further to the south-east probably played an important role in the lagoonal environment, but at present this creek does not contribute water to the lagoon.

The composition of the lagoon water and the nature of the seasonal rise in water level suggest that the greater part of the lagoon water has been derived from the sea and nature of the fauna supports this. The widespread occurrence of brackish water in the Northern Lagoon during times of high river flow shows that the River Murray is a major contributor of water to this part of the lagoon at times of strong river flow. However, much of this water probably leaves the lagoon during the fall in water level. River water does not affect the ionic composition of the lagoon waters to any great extent, and the sea is the predominant source of the dissolved salt content of the lagoon water. The main effect of the river appears to be in diluting the highly concentrated waters from time to time,

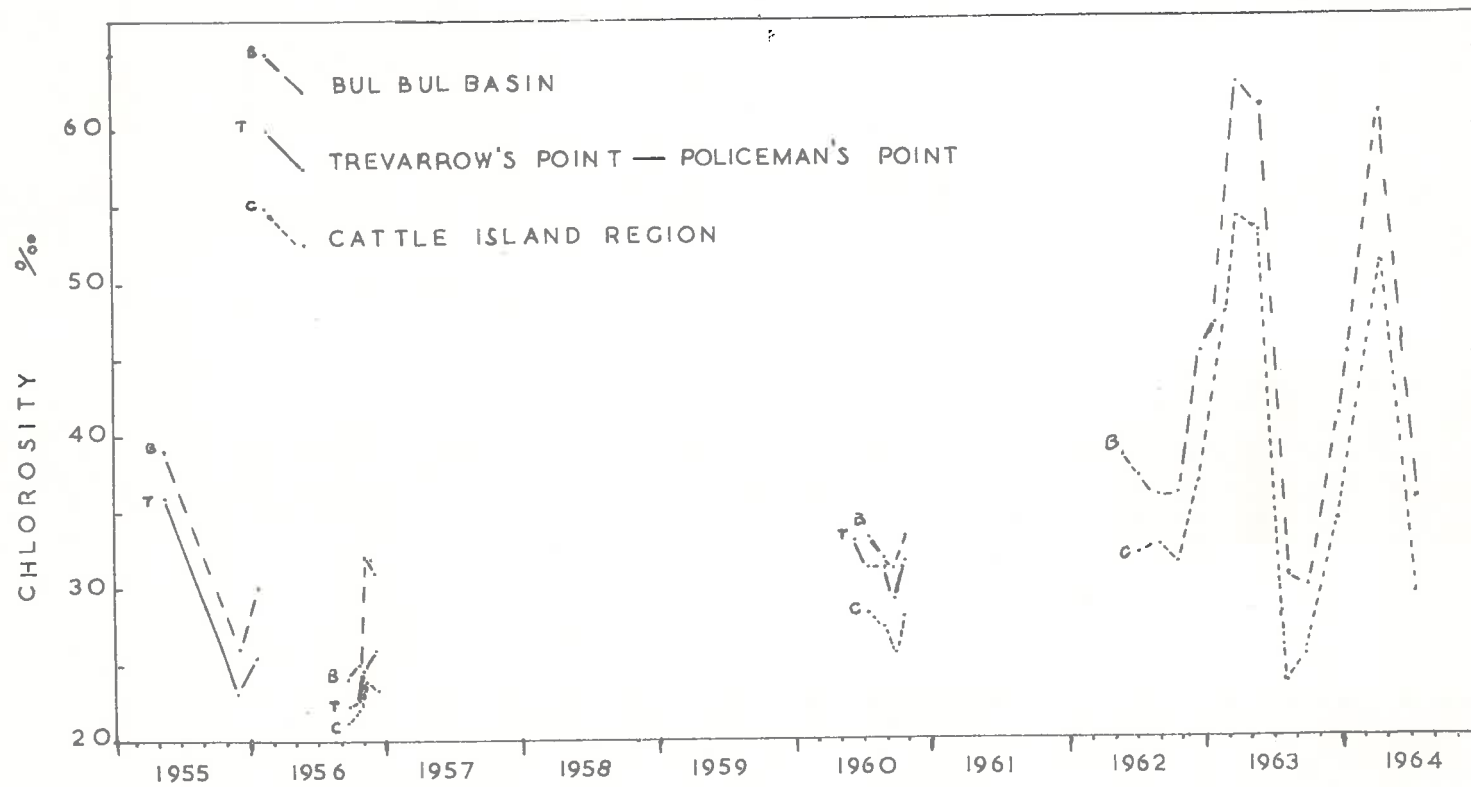


FIGURE 8.

LONG-TERM CHLOROSITY CHANGES IN LAGOON WATERS.

and in this way to prevent a rapid accumulation of dissolved salts from year to year.

The narrow confines of the Hell's Gate Passage act as an effective barrier to the southward spread of brackish waters. Although none was detected during the present investigation, some fresh to brackish water occasionally enters the Southern Lagoon. In the winter of 1963, a local resident tasted water at the shore east of Hack Point and found it relatively fresh. The chlorosity values during that winter were lower than in the previous winter throughout the Southern Lagoon (see Fig. 5) and it appears that a greater proportion of river water came through the Hell's Gate Passage than in previous years.

7. LONG TERM COMPOSITION CHANGES.

Lagoon waters were collected in 1955 and 1957, (Alderman and Skinner (1957) and Skinner (1963)), and in 1960 (von der Borch (1962)), at three localities along the lagoon shoreline. These samples were collected mainly at times of high water level, and at locations where the near-shore waters are relatively deep, so they can be expected to be representative of the conditions in the deeper parts of the lagoon at those localities. These analyses have been plotted, with those collected from the same areas during the present investigation, in Fig. 6. Although the sampling was discontinuous, it covers five periods of low salinity from 1957 to 1964 and shows two important points.

The first is that in the winter of 1957, the Southern Lagoon was occupied by hypersaline waters. This was only a few months after the 1956 flood of the River Murray, which was the greatest on record. It caused an exceptionally high water level throughout the lagoon, and the water level remained high well into the summer of 1956-57. In spite of this high water level, the lagoon waters were not greatly diluted when compared with the salinities prior to the flood, and there was no difference in the composition of the dissolved salts. This indicates that even in exceptional circumstances, the influence of the River Murray on the composition of the waters in the Southern Lagoon is slight.

The second point shown in Fig. 8 is that there was a progressive increase in the chlorosity shown by each of the winter periods between 1957 and 1962. This indicates that there is a tendency for the Southern Lagoon to act as a barred basin in which the salt content increases from year to year. This tendency was interrupted in the winter of 1963 by an influx of water in which the proportion of river water was exceptionally high.

8. SUMMARY.

The aqueous environment of the lagoon is characterized by a wide range of conditions along the length of the lagoon, and by wide seasonal fluctuations. The composition of the salt content of lagoon waters is the same as that of sea water. Conditions in the Southern Lagoon are hypersaline

throughout the year, and the greater proportion of the water in this section has probably been derived from the sea. The Northern Lagoon shows some estuarine characteristics, for although the River Murray does not flow through the lagoon, its waters lead to the development of brackish conditions at times of strong river flow. At other times, the Northern Lagoon shows marine to hypersaline conditions. Seasonal variations lead to the doubling of the salinity and the temperature of the lagoon waters during the summer, and at the same time there is a reduction of longitudinal circulation through the lagoon.

These characteristics have developed because the elongate shape of the lagoon and internal topographic features have severely limited the amount of longitudinal circulation of lagoon waters. Circulation has been further impaired by the absence of connections between the lagoon and the ocean south of the river mouth, and by the absence of streams running into the lagoon from the mainland. Fresh water outflow from Salt Creek may have influenced the lagoonal environment prior to artificial alterations of the natural drainage system south of the Coorong about 1920. There are no records of the compositions of lagoon water before those collected by Alderman in 1955 so the effects of the creek flow can only be inferred from the lagoonal sediments, and will be discussed in a later section.

THE SEDIMENTS AND THEIR DEPOSITIONAL ENVIRONMENTS.

The foregoing discussion on the composition of the lagoon waters and the brief outline of the morphology of the lagoon have indicated that there are a number of different depositional environments within the lagoonal area. In this section it is intended to describe and to relate the sediments and the environmental conditions in the different parts of the lagoon. For this purpose, the discussion has been divided into three parts, each dealing with one of the major divisions of the lagoon. The discussion of the Southern Lagoon, which was examined in greater detail than were the other divisions, is further divided into three parts covering areas which show a degree of natural separation. These are:

The Ephemeral Lagoon, a long stretch of the lagoon which is completely dry during part of the year;

The Bul Bul Basin, a small depression which is in part permanently inundated, but which is virtually isolated from the remainder of the lagoon during part of the year;

The Major Basin Area, consisting of the remainder of the Southern Lagoon, which is a continuous body of water bordered by periodically inundated marginal areas.

THE SOUTHERN LAGOON.(A) THE EPHEMERAL LAGOON.

The southernmost portion of the lagoon is a flat-lying expanse of sand and mud, covered by shallow water in the winter and early spring, but completely dry during the remainder of the year. This area has been called the "Ephemeral Coorong" by Alderman (in press). It is a transitional area, for it has some of the characteristics of the main lagoon, into which it merges to the north, while it shows some similarity to the playa-like lakes further to the south-east, which have been described by Alderman, Skinner and von der Borch (see Reference List).

1. Margin Outlines.

The southern end of the lagoon is considered to be located at a point about 10 miles south of Salt Creek Point. Here, a slightly elevated area, lying up to one foot above the adjacent lagoon floor and covered by low vegetation, predominantly Sampire plants, forms a natural barrier to the southward extension of lagoon waters during most winter seasons. This point marks an important change in the mineralogy of the mud sediments. The muds in the Ephemeral Lagoon to the north are a mixture of aragonite and magnesian calcite. Those on the elevated mud flat to the south are magnesian calcite alone. von der Borch (1962) showed a rapid decrease in aragonite content southward across the mud flat which forms the southern boundary of the lagoon.

Aragonite is not found in the muds further south, even in the lake sediments, which are composed of magnesian calcite and dolomite mixtures (von der Borch (1962)).

The Samphire-mud flat is continuous around the southern end of the lagoon, and extends northward along the western side of the Ephemeral Lagoon, forming a clearly defined western margin in most places. In a few places the Samphire growth appears to be extending out onto the lagoon floor, and is forming projections similar in outline to asymmetrical cusped spits. In these areas, the western edge of the lagoon is rather vaguely defined, and there is a gradational change between vegetated and non vegetated areas. The Samphire-mud flat separates the lagoon from the Recent dunes of Youngusband Peninsula, which are thickly covered by vegetation in this area, and are not encroaching the lagoon.

Apart from a few small sections of Samphire-covered mud flat, mainly at the southern end, the eastern margin is formed by loose sand and shell accumulations, which have been built into a series of low dunes in some sections and covered by thick scrub. A few isolated outcrops of kunkarized sandstone form flat rocky areas and patches of angular pebbles and boulders at, or slightly above, the lagoon floor along the eastern side (see Map, Fig. 17).

2. Topography of the Lagoon Floor.

The lagoon floor is very gently sloping, and the outlines of standing water at times when the area is partly inundated indicate that the central portions are a few

inches below the near-shore region. A gentle, but steeper, slope is shown at the margin, where the lagoon floor rises about one foot across a distance of a few feet to grade into the adjacent elevated mud flat. There is also a very gentle downward gradient to the north, for the lagoon floor is at a level of about 18 inches above the low water level at the southern end, and coincides with that level at the northern end.

Minor topographic irregularities, with a relief of a few inches, are found at the southern end and in the bays along the western side. These are caused by wind- and water-laid deposits of sand, shell and mud. The only major topographic feature in this section of the lagoon is a short channel which connects the southernmost portion of the lagoon to the remainder at a point where the Samphire-mud flats extend almost across the lagoon (see Map Fig. 17). At its narrowest point, the channel is 40 feet wide, and its floor lies about 4 feet below the nearby lagoon floor. To the north and the south, it rapidly becomes wider and shallower and gradually disappears.

3. Hydrology.

The Ephemeral Lagoon is filled with water during late May or early June, and normally the centre is covered by up to 3 feet of water. As discussed previously, the composition of this water is similar to that of the Salt Creek Point area during times of high water level. Some water enters the southern end of the lagoon as surface run-

off from the adjacent swampy areas, but the catchment area is small, and the supply of water is low and intermittent. No lowering of the salinity by rain water run off has been detected, and it is considered that most of the water in the Ephemeral Lagoon is derived from the lagoon to the north. Water which enters the Ephemeral Lagoon has a chlorosity of about 35%, but the chlorosity decreases to about 30% during the winter, following the general trend shown by the whole lagoon. Evaporation during the spring leads to concentration of the waters, and the chlorosity rises to about 40% before the water flows out of the Ephemeral Lagoon in response to the seasonal fall in water level throughout the lagoon.

The whole of the Coorong Lagoon is susceptible to wind-induced water movements, particularly when strong winds blow along its length. These movements are accentuated in the Ephemeral Lagoon and large areas normally covered by shallow water can be exposed by southerly winds. Northerly winds lead to a rapid rise in water level and during storms the water level may rise to 2 or 3 feet above the normal level. During the winter of 1964, the water level rose sufficiently high for the water to spill over the southern end of the lagoon into the lakes as far south as Cantarra Homestead, about 3 miles to the south-east. Similar extensions to the lagoon may have taken place in the past, but it appears that they are exceptional, and the above instance was the first since the widespread flooding that accompanied the 1956

flood of the River Murray.

4. Sediments.

(a) Sediments and their distribution.

The floor of the Ephemeral Lagoon is mainly a flat expanse of pale grey sand, on parts of which a thin veneer of white calcareous mud has been deposited. The highest mud content is found in the southernmost end of the lagoon, in a small section which is almost completely severed from the remainder of the lagoon. This area is largely covered by muddy sands containing up to 25% calcareous mud, but in the marginal zone the mud content rises to above 80%. These muddy sediments form a thin veneer a few inches thick above grey sands which contain only about 5% mud. In the remainder of the Ephemeral Lagoon, muddy sediments are confined to a marginal zone along the western side of the lagoon and along parts of the eastern side. Areas of Saphire growth along the western side show a mud content of about 50%, but away from the growths the mud content is less than 25%.

Concentrations of small gastropod tests and mats of coarse algal fibres form at the strandlines during periods of inundation. During the summer, the mats of algal fibres desiccate and disintegrate. Much of the shell material blows across the lagoon to the eastern shoreline, where it is added to low dunes, which contain a high proportion of lagoonal shell material. Along the western shoreline, some of the shells form permanent accumulations close to the

shore, where they are in the shelter of the bushes along the shoreline, or in sheltered embayments and areas of Samphire growth.

(b) Composition.

(1) Sands.

The sands of the Ephemeral Lagoon are well sorted and moderately well sorted, and predominantly of fine and medium grain size, (see Table 4 and Fig. 14). They contain between 40% and 60% of calcareous grains, which are of two varieties. The predominant variety consists of well rounded shell fragments similar to those of the Recent dune sands. The second variety consists of angular to subrounded fragments, many of which are recognizable as fragments of lagoonal shells. The quartz grains are also of two varieties. Between one half and two thirds of the grains are subangular to subrounded, with smooth glassy surfaces, and appear similar to the quartz grains of the Recent dune sands. The remaining quartz grains are more commonly angular, and have a sugary surface texture which is similar to that found in the corroded grains from the weathered Pleistocene dunes. The high proportions of the glassy quartz grains and of calcareous grains similar to those of the Recent dunes, show that the Recent dunes have been the source of the greater part of the sand in the Ephemeral Lagoon. Other sand sized material has been derived from the weathered Pleistocene dunes and by

fragmentation of the lagoonal shell material, but the high incidence of indeterminate grains did not allow quantitative assessments of the relative importance of the three sources.

(11) Muds.

The muds of the Ephemeral Lagoon are highly calcareous, and contain between 80% and 90% calcium carbonate. The remainder consists of silt sized quartz and a fine brown residue which gives no X-ray pattern, but which may possibly be organic detritus. The calcareous component is a mixture of aragonite and magnesian calcite, with aragonite the more abundant. The magnesium content of the calcite, determined by measurement of the d(112) spacing in X-ray powder photographs, has an average value of 6.0 mol % $MgCO_3$, (see Table 2), which is close to the average magnesium content of surface calcite in the Bul Bul Basin to the north.

(c) Sedimentary structures.

The sediments containing sand and mud mixtures show some well developed stratification, due to alternations of laminae which show differences in mud content. The laminae are clearly shown, but their boundaries are gradational. Gastropod and lamellibranch tests, and tabular shell fragments are often oriented parallel to the lamination. In the more muddy sediments under the areas of Sapphire growth, mud-cracks, root cavities and burrows are common, and the

lamination is destroyed. In the sand sediments, the only structures shown are the horizontal orientation of large shells and fragments, and some poorly defined shelly beds.

At the southern end of the lagoon, green-brown colored algal growths form small rounded mounds a few centimeters in diameter and one or two millimeters high. The margins are undulating, and the tops flattened. The algae form a very loose mat, 1 or 2 mm thick, permeating the underlying sediment with thin fibres less than 0.5 mm long. Below the surface there is a sequence of laminated sandy muds similar to the laminated sediments in the remainder of the lagoon floor, in which the compositional lamination has been accentuated by dark brown laminae containing desiccated algal fibres. The algae have evidently been active during the accumulation of this sediment, but they only outline a compositional lamination similar to that away from the algal-covered areas. It is unlikely that the algae caused this lamination to develop.

5. Organic remains.

The sediments of the Ephemeral Lagoon contain abundant organic remains derived from the Recent dune sands, but these are regarded as being of detrital origin, and will not be further discussed. The remains of organisms which lived in the lagoon area can be divided into two groups. The validity of this grouping and the stratigraphic relationships between the two groups is best seen in the areas to the north of the Ephemeral Lagoon, and the constitution and significance

TABLE 1.

Large Lamellibranchs Characteristic of Fauna 1.

Notospisula trigonella Lamarek 1818.

Flavomala gonacioides Reeve 1857.

Mytilus planulatus Lamarek 1819.

Katylusia spp. Romer 1856.

Eumarcia fumigata Sowerby 1853.

Venerupis sp. Lamarek 1818.

Mecomonas deltoidalis Lamarek 1818.

Ostrea sinuata Lamarek 1819.

of the groups will be discussed more fully in a later section. The two groups have been termed Fauna 1 and Fauna 2.

Fauna 1, in the Ephemeral Lagoon, consists of the organisms listed in Table 1. The shells of many of these species are much larger than those of Fauna 2, and belong to species that live today in normal or near-normal marine environments. None are at present found alive in the Southern Lagoon. Although many of the shells are moderately to strongly abraded, many others show no signs of abrasion, and complete shells are widespread and occasionally abundant. Shells of one variety, Katylesia sp. have been found in the sands of the Ephemeral Lagoon in their position of growth. It is therefore considered that the shells are the remains of organisms which grew in the lagoon, and that they were not transported from localities outside the lagoon area.

The organisms of Fauna 2 are characteristic of a later phase in the development of the lagoonal environment. They indicate a different range of water compositions, varying from brackish to hypersaline. In the Ephemeral Lagoon, the most abundant members of this group are the small gastropod Coxiella confusa (Smith, 1894) and the small lamellibranch Diaphoromactra versicolor (Tate, 1886), both of which are known to be euryhaline. Ostracod tests are common in some samples, particularly those containing a high proportion of mud, and most belong to the species described as ^{Species} ~~Type~~ A on page 125. The foraminifera Ammonia beccarii (Linne, 1758)

is common and oogonia of the aquatic plant Chara spp. occur rarely in the sediments along with the above members of Fauna 2.

In the Ephemeral Lagoon, shells of both faunal groups are found together in abundance. Those of Fauna 2 are found in the sequence of muddy sands and sandy muds, but tests of Fauna 1 are very rare in those sediments. In the central sandy areas, tests of both groups are found together in the topmost one or two inches, but below this depth, the tests of Fauna 2 are very rare to absent, whereas the members of Fauna 1 are found down to a depth of at least 24 inches. This distribution suggests that the Fauna 2 post-dates Fauna 1, and this relationship is clearly shown in other parts of the lagoon.

6. Sedimentary processes.

The persistence of gougings made by swans while feeding in the Ephemeral Lagoon during periods of inundation, and of wheel marks left by vehicles during periods of emergence, indicate that there is little transportation and deposition of sand sized material in this area by either wind or water. Wind blown sands pass over the area during the summer, but most of the sand appears to be blown across to the low dunes along the eastern shoreline. The rate of deflation of the lagoon floor is low, for the sands are firmly bound together by interstitial salt deposits after they have dried. The shell material forms a slightly concentrated lag deposit on the lagoon floor, and the shells are often broken and

corroded. The pieces are angular, and their breakdown appears to be the result of chemical leaching, growth of salt crystals, or some other result of exposure to the atmosphere and the sun, rather than the mechanical effects of wind or water.

Water circulation during the periods of inundation plays an important role in the deposition of the muddy sediments. Wind and waves agitate the waters of the permanently inundated areas to the north, and drive sediment laden waters south into the Ephemeral Lagoon. Here, part of the suspended mud settles before the water flows back to the north. Mud cracks have been observed to fill with floccules of mud which was left as the waters receded. Generally the incoming waters are agitated by high winds, and the water level does not drop until the velocity of the wind falls, or its direction changes. In either case the outflow is accompanied by a lesser degree of bottom agitation, for the winds will pass over a smaller fetch of water in the case of a change in wind direction, and some of the material which settled out of suspension is left behind as the waters recede. There is, therefore, a tendency for mud to be transported southwards into the Ephemeral Lagoon, and to permanently accumulate there.

The sand area in the centre of the Ephemeral Lagoon is kept relatively free of permanent mud accumulations by wave action and water circulation, and this is largely a non-depositional area. The muds tend to accumulate in sheltered

areas, and in the very shallow marginal areas, where agitation and circulation of the waters is considerably lessened. The most sheltered areas are the very shallow areas under the shelter of the western shoreline, for this part of the lagoon is sheltered from the direction of the prevailing winds. Even at times of northerly winds this part of the lagoon is moderately calm, for a wide expanse of very shallow water at the shoreline dampens wave action and prevents the stirring of the bottoms muds. The permanent accumulation of muds in the marginal areas is assisted by the periodic emergence, for dessication compacts the mud left each winter, and the dried mud retains much of its coherence during subsequent inundation.

7 . Summary.

The Ephemeral Lagoon is characterized by alternating periods of inundation with hypersaline waters, and periods of complete emergence and dessication. During the period of inundation, the waters are shallow and subjected to wave agitation and water circulation caused by the action of winds on the lagoon waters. The agitation is not sufficiently intense to cause much movement of sand sized material, but is sufficient to keep most of this part of the lagoon free of permanent mud accumulations. Permanent deposits of mud are forming only in the more sheltered marginal and terminal areas. The rate of deposition is slow and the deposits formed are very thin when compared with the mud sequence in the areas to the north. The general appearance of the sand

and mud mixtures of this section of the lagoon is similar to that of the sediments in the lakes south of the lagoon. The composition of the lagoonal muds is similar to that of the muds in the Bul Bul Basin to the north, but they have a slightly higher calcareous content than the latter. It is considered that much of the mud deposited in the Ephemeral Lagoon has been derived from the southern part of the permanently inundated lagoon, and was transported southwards in suspension at times of very high water level. The waters of the Ephemeral Lagoon are not subjected to a long period of evaporation, and there is very little algal or other aquatic plant life over the greater part of the lagoon floor in this section. These two factors probably limit the amount of physico-chemically or biochemically deposited calcium carbonate that forms in this part of the lagoon.

(B) THE BUL BUL BASIN.

Near the Bul Bul seep, the lagoon floor slopes gently under permanent water to form a small shallow basin, clearly defined on three sides and grading into the Ephemeral Lagoon on the southern side. The basin, in this discussion called the Bul Bul Basin, is about two and a half miles long, one mile wide and, at its deepest part, the basin floor lies about four feet below the low water datum.

1. Margin Outlines.

Its northern limit is defined by a sand bar, about half a mile wide, extending completely across the lagoon westward from Salt Creek Point. The central half of the bar lies close to the low water datum and its surface slopes gently to a depth of one foot towards its southern edge, where it drops more steeply to meet the almost flat-lying basin floor at a depth of about 3 feet below the low water level. During the summer, a thin layer of a few inches of water connects the Bul Bul Basin to the Salt Creek Basin to the north, but at times of very low water level, the connection may be completely severed.

The low, unconsolidated sand dunes along the eastern side of the Ephemeral Lagoon continue along the shore of the basin to a point east of Bul Bul, where they give way to partly lithified and kunkarized Pleistocene sand dunes. The coastline north of this point is rocky, with low cliffs and steep slopes rising up to about twenty feet high. At their base is an erosional platform up to two hundred feet

wide, composed of arcuate rocky projections surrounded by grey sands. The development of this type of coastline is discussed in a later section.

The western coastline consists of a series of smoothly rounded projections and embayments, formed by the unconsolidated Recent dunes of Younghusband Peninsula, which are actively advancing into the basin along much of this shoreline. Most of the western shore is a sandy beach, but in two areas there are expanses of lagoonal muds which have been uplifted by the advancing dunes, as described on page 177.

2. Topography of the Lagoon Floor.

The lagoon floor slopes inwards on all four sides, towards a fairly flat central floor (see Fig. 18). The floor is smooth, except in one area on the eastern side, where three outcrops of kunkar form a semicircle with a diameter of 250 feet, outlining an eroded dune. The outcrops rise almost vertically up to four feet above the surrounding sediment, with a few sections rising to one foot above the low water level.

3. Hydrology.

The waters of the basin reflect the cyclic variation of water level and water composition described previously. The annual water level oscillation influences water composition in this basin more than in the remaining basins. During the high water period, the sand bar at Salt Creek Point is covered by three or four feet of water, and the

water composition of the Bul Bul Basin is not markedly different from that of the Salt Creek Basin. As the water level drops and evaporation leads to an increasing salinity throughout the lagoon, the salinity of water in the Bul Bul Basin increases at a faster rate, because of the more shallow depth of water present. This differentiation is not destroyed by interchange of water, and the difference in chlorosity between the two adjacent basins rises to as high as 15‰. This lack of water exchange indicates that at times of low water level the sand bar forms an effective barrier, as a result of its width and shallow nature. This compositional difference persists until the lagoon water level starts to rise in autumn, when dilution by incoming water, and increased ease of water exchange, lower the concentration of water to the south of the sand bar. Throughout the year, the water of this basin is hypersaline, showing chlorosity values ranging from about 30 to 35‰ in winter to about 60 to 65‰ in summer.

4. Sediments.

The sediments of the basin can be divided into two groups with distinctive lithologies and distribution patterns. The first consists of coarse material, sand and shell deposits, the surface deposits of which are largely confined to the margins of the basin. The second group consists chiefly of finer sediments and light organic detritus which are mainly found in the deeper central portion of the basin.

(a) Marginal Sediments.

On all four sides, the marginal sediments are predominantly sand and shell. Two distinct types of sand are recognisable.

Along the northern, eastern and southern margins, the sands are moderately, sorted, fine to coarse grained, with a widely varying carbonate content. These sands are similar to those of the platform areas described in the following section. Along the western margin a second type of sand is found. These are well sorted, fine to very fine sands, with a more uniform carbonate content, (50 to 60%). They are being actively eroded from the modern dunes of Younghusband Peninsula, and locally redeposited by water and wind action along the western shore of the basin.

(b) Central Sediments.

The central portion of the basin shows a sequence of calcareous muds and interbedded layers of concentrated algal and ostracod remains, with a few shell and sand layers. The sequence is three feet thick in the eastern part of the section shown in Fig. 18, but in the remainder of the basin, the cores show a sequence of muds about five feet thick without revealing its base.

The muds are black or dark grey when first collected, down to a depth of about six inches. Below this they rapidly grade to pale grey and white, with a few dark grey and green-grey bands. The ostracod layers are commonly grey, but a few are coloured dark green by a greasy green

pigment on the exterior of the tests. The algal fibres are either dark green or pale yellow-green, and often show alternating layers of these two colours. All these colours are destroyed by the oxidising action of hydrogen peroxide, leaving the ostracods transparent, and the mud and fibres white. This suggests that the colouration is due entirely to organic pigments or to iron sulphides of a very fine grained form.

(1) Sediment types.

OSTRACOD LAYERS.

The ostracod layers consist of laminae and thin laminae, generally less than 1 cm thick, but ranging up to 5 cm thick. They seldom contain interstitial mud matrix, but may contain a small percentage of granular mud aggregates up to 0.3 mm in diameter and some shell fragments. The tests are loosely packed and some laminae show a predominance of horizontally oriented tests. The tests are very thin and transparent, and appear to belong to one species, (Species A, see page 125).

ALGAL FIBRE LAYERS.

Algal fibres are concentrated in layers up to 10 cm thick, which are made up of mat-like laminae of interlocking fibres, approximately 0.2 mm long and 0.01 mm in diameter. The laminae are from 1 to 10 mm thick and are clearly differentiated, often by striking colour changes, with alternations of dark and pale green, and yellow laminae. The mats contain little or no interstitial mud, but they may be interlaminated with clearly defined laminae of mud or

ostracod tests. The fibres are horizontally oriented and interlocking, forming a moderately coherent mat.

SAND.

Sands occur in some cores in the central portion of the basin, as shown in Fig. 18. A prominent sand and shell horizon delineates the base of the mud sequence in much of Section A, and other cores show a surface layer of a few inches of sand above the muds. Isolated sand horizons in cores C.9, C.10 and C.13 have probably been derived from around the nearby kunkar outcrop described on page 86. These sands probably represent intertonguing of the marginal sands and the central sediments at various times during the filling of the basins.

MICROCOQUINA.

Laminae and thin laminae composed of concentrated remains of Armonia beccarii, Coxiella confusa and Diaphoromactra versicolor are found in the lower parts of some cores. They are loosely packed, and contain very little mud, but they may contain a high percentage of sand.

MUDS.

Calcareous muds form the bulk of the central basin sediments.

(11) Texture.

Most of the muds show a granular texture, with medium sand-sized aggregates in the topmost few inches and fine to very fine sand-sized aggregates in the remainder. In the surface muds the aggregates are loosely packed, with open

PLATE 15.

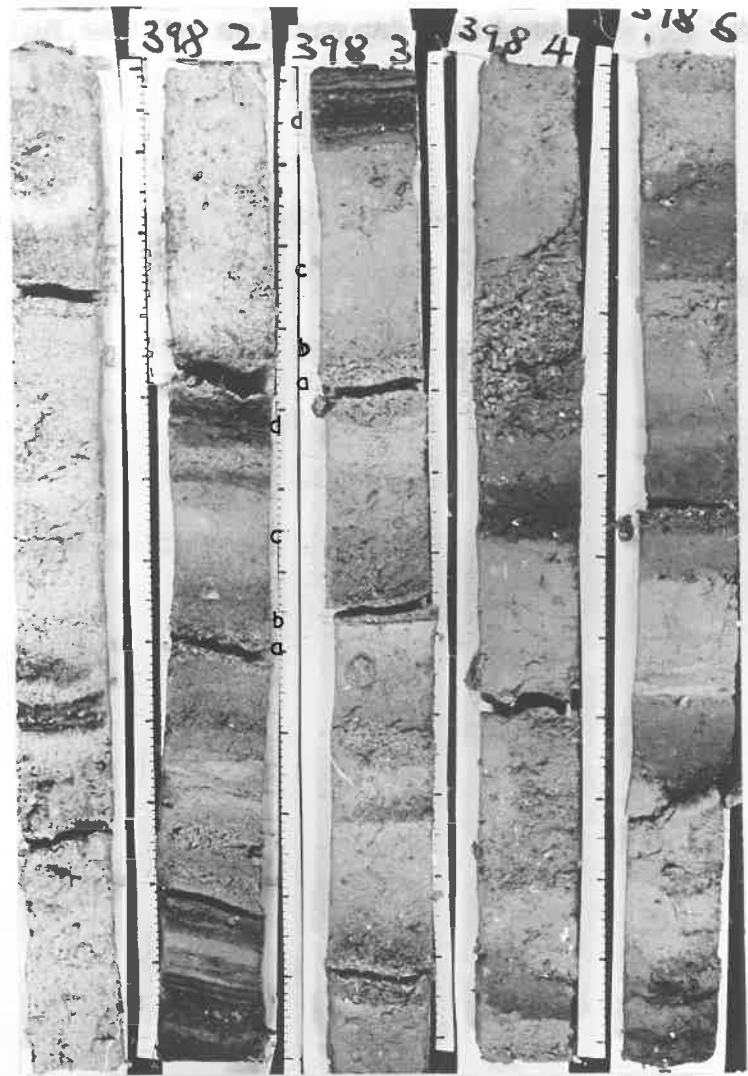
Sediments of the central depression of the Bul Bul Basin.

A. Core no. C.8, showing ordered sequences of sediment types.

- a. Ostracod lamina.
- b. Granular mud.
- c. Homogeneous mud.
- d. Laminated fibre, with some mud laminae.

Scale is in inches.

B. Mud beds and laminated fibre beds exposed in the folded sediments at Bul Bul Seep. The scale is 8 inches long.



intergranular pore space, but below a depth of six to twelve inches the degree of compaction increases, and the aggregates tend to merge, destroying the intergranular pore space.

Pelletal muds form only a small portion of the sequence. A few scattered pellets are found in most cores, but in three cores there are muds which show widespread pelletization, forming a subsurface bed of pelletized and slightly pelletized mud in the north western corner of the basin, (see Cores C.12, C.14, and C.24 in Fig. 18).

Laminated mud is less common on this basin than in the Salt Creek Basin to the north. There are a few thin layers of laminated mud in the cores, but most are less than 5 cm thick. Only cores C.2, C.6 and C.14 show layers of laminated muds exceeding 5 cm in thickness. The lamination is the result of both textural variations and alignment of scattered algal fibres, (see Plate 15).

(111) Composition.

Table 6 shows a summary of the mineralogical composition of the lagoonal muds in the Bul Bul Basin. The muds are predominantly calcareous, but include some silt sized quartz and organic matter. No argillaceous clays were detected in the X-ray diffraction photographs of samples of the complete mud fraction, but faint traces were detected in photographs of acid residue material. The carbonate content of samples from core C.2 was ranged from 76% to 89% of the dry weight. The remaining material was

predominantly silt-sized quartz and a little argillaceous clay. There was no systematic variation in the vertical distribution of carbonate content in this core.

The calcareous component of the surface muds consists of a mixture of aragonite and magnesian calcite, see Table 6 . The relative intensities of the X-ray patterns of these two minerals show that aragonite is the more abundant. The ^{average} magnesium content of the calcite in surface samples is 7.3 mol % MgCO_3 . This is slightly higher than the magnesium content of calcite in the Ephemeral Lagoon, but the difference is not statistically significant.

Below the sediment surface, there is some variation in the composition of the calcareous component of the muds. In the two cores investigated, the aragonite : calcite ratio decreases below a depth of about 20 inches. The aragonite content remains relatively low down to a depth of about 40 inches, below which depth the aragonite : calcite ratio increases - see Table 6 . Subsurface calcite shows a magnesium content which is markedly higher than the magnesium content of the surface calcite - see Table 6 .

(iv) Sedimentary structures.

The sediment sequence in the central portion of the basin shows a well developed but unevenly distributed stratification - see Plate 15 . The stratification is caused by marked lithological variations, lamination within fibre beds and, to a lesser extent, by textural and colour variations in the muds.

Some cores show a rhythmic succession of ordered lithological and textural variations, in part similar to graded bedding - see Plate 15 . These successions are best shown in cores along the western side of the basin, but in some of the other cores there are less clearly developed arrangements which are probably imperfect reflections of the same features. A typical ordered sequence shows three distinct parts, a basal ostracod layer, a central mud layer, and an upper laminated unit.

The basal ostracod unit is commonly 1 to 10 mm thick. It rarely contains mud matrix and shows a sharply defined lower contact above the underlying sediment. The top is distinctly gradational over a distance of 1 to 5 mm, showing a decreasing content of ostracod tests and an increasing mud content as the ostracod layer grades into the overlying mud unit.

The central mud unit shows a graded sequence of mud aggregates. The lowermost part of the unit is composed of granular mud, in which the aggregates are 0.2 to 0.3 mm in diameter. They are loosely packed, leaving an unfilled network of intergranular pore spaces. This granular mud grades upwards into more finely granular mud in which the aggregates become progressively smaller, ranging from 0.05 to 0.1 mm in diameter. At the same time, the aggregates become less coherent and tend to merge, destroying the intergranular porosity. The granular mud grades upwards into homogeneous mud in which there is no recognisable texture.

Accompanying this textural change within the mud unit, there is commonly a gradual decrease in the content of ostracod tests. They are generally common to abundant in the lower parts of the unit, and grade to rare or absent in the homogeneous part of the unit. The thickness of the complete mud unit varies between 1 cm and 8 cm, with the lowermost one-half to two-thirds showing a recognisable granular texture.

Above the mud unit is a laminated unit, which consists most commonly of laminated algal fibres, but sometimes of laminated mud. The contact with the underlying mud unit is either an abrupt transition, or shows a transitional zone of alternating mud- and fibre- laminae passing upwards into laminated fibre along. The laminated unit varies from 1 to 14 cm. in thickness, but is most often less than 5 cm. thick. Its upper surface is marked by a sharply defined break, above which is found an ostracod layer or a bed of granular mud, commonly marking the base of a similar sequence.

Incomplete sequences occur in which the basal ostracod lamina is missing, but the overall appearance of these does not greatly differ from that of the normal sequence. It is likely that the presence and the thickness of this basal unit are easily influenced by slight water movements so that its absence has no real significance. Other ordered and partially ordered sequences show a basal ostracod lamina, which grades upwards into a graded sequence of granular mud with a gradual decrease in ostracod content. There is no laminated unit

and there may be no homogeneous mud at the top of the mud unit. These may be partially developed sequences which are lacking part of the succession either because that portion was removed after its deposition, or because the depositional conditions did not allow its formation.

5. ORGANIC REMAINS.

The part of the basin floor which is permanently inundated is partly covered by patches of green filamentous algae in which the fibres are several cm long and about 0.02 mm thick. In the past, similar patches may have been the source of the concentrated algal fibres in the sediment sequence, but no similar accumulations are forming on the lagoon floor at the present time. Algal fibres form mats along the present shoreline, where the fibres are concentrated by wave action at times of strong winds. These deposits are not likely to be incorporated into a succession of muds and are not regarded as analogues of the laminated fibre beds in the mud sequence.

Living specimens of the aquatic plant Chara were collected from the basin floor and the plant is common throughout the Southern Lagoon. The oogonia of this plant are widespread but rare throughout the mud sequence in the Bul Bul Basin.

Ostracod tests are the most abundant type of organic remains preserved in the mud sequence of the basin. They predominantly belong to an unidentified cyprid species, designated as "Species A" and described on page 125 .

Remains of other organisms of Fauna 2, Coriella confusa,

Diaphoromactra versicolor and Ammonia beccarii, are abundant in the mud sequence, and are often concentrated in laminae of microcoquina. Their shells are common to abundant in the surface sands along the northern, eastern and southern sides of the basin. In places they are concentrated by wave action, particularly along the high water strandline.

The large lamellibranchs of Fauna 1 are abundant in the lowermost parts of the sands below the mud sequence and in some of the surface sands around the northern, eastern and southern sides of the basin. The sands along the western side of the basin are largely derived from the Recent dunes, and contain very few lagoonal shell remains. The bulk of their organic content consists of rounded fragments and complete small tests of organisms which are typical of the ocean beach.

6. Depositional Processes.

The lagoonal sands form a marginal belt around three sides of the basin, and extend westwards under the mud sequence as far as the centre of the basin, (see the map Fig. 17 and the cross sections in Fig. 18). Probing at the southern and northern ends shows that the marginal sands plunge steeply under the overlapping muds. This relationship suggests that these sands form a basin like framework within which the central muds and associated sediments have accumulated. The accumulation of muds in the deeper parts of the basin is probably a response to a lower intensity of bottom agitation in the deeper water. Patches of algal

growth on the mud surface have probably aided the deposition of the lighter sediments.

The marginal areas have a low mud content, as wave action can periodically remove most of the mud that settles there. There is now little movement of sands over most of the marginal areas, except in those parts which are close to either the high or the low level. At the high water level, sand ridges and steep beaches have been constructed by wave action. Below this level, the sand is compacted, and forms a relatively flat surface. Generally, Fauna 2 shells are found only close to the surface, indicating that there is little agitation, transportation and re-deposition of the sands over the greater part of the platform surface there. Thus, most of the marginal area is similar to the Ephemeral Lagoon, being an area which is subjected to very little erosion or deposition at the present time. Close to the low water level, there is evidence of some transportation and deposition of sands. The cross-sections shown in Fig. 18 reveal a thin layer of sand extending out into the central portion of the basin over the mud sequence, indicating that in parts of the basin, lateral spreading of the sands is taking place. The isolated sands in cores C.9, C.10 and C.13 were probably formed by the redistribution of sands surrounding the dune remnant which rises from the basin floor nearby. This remnant is surrounded by a belt of lagoonal sand, which has now been covered by a layer of mud, a few inches thick.

Along the western shoreline, extensive movement of sand is taking place at the base of the encroaching sand dunes. Waves attack the loose sands and cut into the dunes, spreading large quantities in the form of wide sand shelves in front of the dunes, (see Plate 17).

Laminated fibre beds are mainly confined to the western side of the basin, which is the side of the basin most sheltered from wave action. As discussed earlier, there are no analogous deposits forming on the present basin floor, so that their origin is uncertain. It is likely that they were concentrated by the action of water, and, as the fibres float at the surface or remain in suspension, they could have become concentrated in relatively sheltered areas and there settled to form mat like deposits. Their relationship with the underlying muds precludes a concentration by wave action as takes place along the shorelines. Whether the concentrations are the result solely of a mechanical process, or are partly the result of a prolific development of algae under some climatic or hydrological control, is not known.

The rhythmic and ordered sequences described earlier are best shown in the same parts of the lagoon as the optimum development of the fibre beds, and the processes responsible for one are probably closely linked to those responsible for the other. The repetition of an ordered sequence of sediment types indicates some form of cyclic variation in the depositional environment. The nature of

the environmental feature controlling this type of deposition are not known, but it seems that a mechanical control of some type is partly responsible. The sharply defined lower contact of most units strongly suggests that there was a brief period of erosion at the commencement of each cycle. This was followed by a period of deposition, with gradational changes in the nature of the sediment being deposited. The basal portions of each cycle are probably a result of mechanical sorting. The ostracod laminae probably formed soon after the agitation responsible for the erosional break and their concentration achieved by water which moved sufficiently to keep mud in suspension. The graded succession of granular mud was probably a response to a continuing decrease in the intensity of water movement, and it is possible that the complete mud unit of each cycle reflects such a gradational decrease. Alternatively, the upper part of the mud may have been deposited long after the completion of the episode responsible for the erosion, and subsequent deposition of the ostracod lamina and the basal part of the granular mud. It is likely that the erosion, and deposition of the lowermost part of the cycle took place in a period of, say, days or even hours, but the period of time represented by the remainder of the cycle is not known. It seems more probable that it took a period measurable in years, following some sudden event which caused the basal disconcordance.

7. Summary.

The Bul Bul Basin forms a topographically distinct portion of the lagoon at the southern end of the permanently inundated section. Because of its virtual isolation from the remainder of the lagoon at times of low water level and its shallower depth, summer salinities are higher than in the remainder of the lagoon. The broad features of this basin are similar to those of the basin areas further to the north, which will be described in the following section. However, there are some minor differences in the nature of the sediments which have accumulated in the Bul Bul Basin.

The surface sediments are similar to those of the adjoining Salt Creek Basin. The subsurface muds in the known portion of the sediment sequence are all highly calcareous, as are the uppermost 5 feet of the muds in the Salt Creek Basin. The decrease in aragonite content in the Bul Bul Basin sequence is not accompanied by or close to a marked change in total calcium carbonate content as it is in the Salt Creek Basin. Further, in the Bul Bul Basin, the proportion of aragonite increases towards the end of the known sequence.

The development of rhythmic cycles of sedimentation is confined to the Bul Bul Basin, as is the development of relatively thick laminated layers of algal fibres. In the lagoon to the north, laminae composed entirely of algal fibres form a very minor part of the sediment sequence, although fibres may be abundantly scattered through beds

of laminated mud.



(C) THE MAIN BASIN AREAS.1. Morphology.

North of Salt Creek Point, the width of the Coorong abruptly increases and its outline becomes highly irregular. The area occupied by the lagoon has two topographically distinct parts - shallow marginal platform areas on either side, and a deeper central depression. This differentiation was briefly outlined in the previous section on the Bul Bul Basin, but as it is more clearly developed in this section of the lagoon, it will be described in more detail in the following pages. In three localities, extensions of the platform areas from both sides of the lagoon have narrowed the central depression and divided it into four interconnected basin-like sections. These have been named the Salt Creek, Policeman's Point, Cattle Island, and the Stony Well Basins. These basins are connected by narrow passages of deep water, whereas the Bul Bul Basin is a topographically isolated depression at their southern end.

(a) The Eastern Margin.

Between Salt Creek Point and Wood's Well homestead, the eastern shoreline of the lagoon is very irregular, consisting of a series of large headlands and embayments upon which numerous smaller promontories and bays have been superimposed. The irregularities reflect variable resistance to erosion by the partially indurated sand dunes which form the adjacent land surface. The degree of resistance varies as a result of changes in the degree of kunkar formation within the dunes,

PLATE 16.

Platform area along the eastern shore of the lagoon to the east of Stony Well Island. Note the semi-circular and sinuous traces of the truncated kunkar of the eroded dunes.



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or, more rarely, is controlled by the presence of largely unweathered and well cemented scollanite. North of Wood's Well, major headlands are absent, and the shoreline shows numerous small scale irregularities along an almost straight coastline.

Low cliffs and steep slopes rise to about 50 feet above the shoreline where dunes have been cut open by erosion. The interdunal swales form sand-filled bays, inland from which smooth surfaces gently slope upwards, following the non-eroded dune topography. Large boulders and heaps of kunkar rubble lie at the base of the cliff in many places, while in many others scree-like slopes of sand have formed by weathering of the cliff face. Most of the cliff-line is separated from the normal high water level by a beach deposit of sand and shell.

Beyond the shoreline, an almost flat platform of sand and rock extends into the lagoon. Long sinuous to arcuate outcrops of kunkar form the framework of the platform, showing a maximum elevation of two to five feet above the low water datum - see Plate 16. Loose grey sand surrounds the outcrops, and constitutes the greater part of the platform surface in most localities. The smooth sandy surface slopes gently downward away from the shore. The platform varies greatly in width from about 100 to 4000 feet, but it is present in some form along the whole of the eastern side of this section. It extends westwards and envelopes most of islands and many of the reefs within the lagoon, so that

they form a part of the eastern platform. Many of these reefs and islands are joined to the eastern shore by dry land during periods of low water level.

The outer limit of the eastern platform is marked by a break in the slope of the lagoon floor. The surface gently slopes down to a level about 2 to 5 feet below the low water level, then drops more suddenly, the steepness and duration of the decline depending on the level of the nearby basin floor. In many parts of the Salt Creek and Policeman's Point Basins the lagoon floor drops steeply from about 5 feet to about 11 feet below the low water level over a distance of 200 to 400 feet, see Cross-section E in Fig. 18. Everywhere in these two basins there is a clearly defined marginal slope at the outer edge of the eastern platform, although in some places (e.g. near the mouth of Salt Creek) the slope is more gentle. The sand bar at Salt Creek Point is a continuation of the eastern platform, but at its western end it is largely covered by a sheet of reworked dune sand extending eastwards from a sand drift on Young-husband Peninsula.

In the Cattle Island Basin, the eastern platform is similarly defined by a steep marginal slope, but the sloping surface does not descend as far as in the two basins to the south. Further to the north, in the Stony Well Basin, the difference in depth between the platform and the adjacent basin floor becomes even less, and the marginal slope is poorly defined or absent altogether.

PLATE 17.

Shelf of sands reworked from the Recent dunes, along the western shore of the lagoon at locality F3, near Salt Creek Point. Note the folded muds at the base of the advancing dune.



Within wider stretches of the platform, there are a few depressed areas where the surface lies up to two feet below the general surface level. Many of these depressions are continually connected to the main water body, but a few isolated patches of water are left on the platform by the seasonal drop in water level. These soon disappear as the water evaporates or soaks into the sand, but one large depression due east of Trevarrow's Point retains an isolated sheet of water throughout the summer.

(b) The Western Margins.

Two types of shoreline are found along the western side of the lagoon.

The first forms the western shoreline of the greater part of the Salt Creek Basin, and is the same as the western shoreline of the Bul Bul Basin. It shows extensive areas where Recent sand dunes are moving eastwards into the lagoon, separated by a few stretches where the dunes are fixed by vegetation. Narrow sand shelves are formed by the erosion of the loose dune sand, and extend into the lagoon, often with steep slip faces at their edges, (see Plate 17). Northwards from a point across the lagoon from Trevarrow's Point, moving sand drifts which reach the lagoon are rare, and Recent dunes fixed by vegetation border the shoreline over a short interval.

North of Wataleera Bay the character of the shoreline changes and low cliffs, out into kunkarized Pleistocene dunes, border the lagoon. The western shoreline there

has an appearance similar to that of the eastern shoreline. It shows an irregular outline, with a platform of sand and rock extending eastwards into the lagoon. The western platform includes some of the mid-lagoon islands and reefs not enveloped in the western platform. The platform surface slopes gently downwards towards the floor of the basin and generally there is only a vaguely defined break in slope at the outer edge. The kunkarized dunes along the western side of the lagoon are discontinuous (see Fig. 17) and between the outerops Recent dunes border the lagoon. These are generally fixed by vegetation and are spilling sand onto the platform in only a few localities. The eastern and western platforms join in the vicinity of Hack Point, but everywhere else they are separated by the relatively deep waters of the central depression.

(c) The Central Depression.

(i) The Salt Creek Basin.

In this area the marginal slope of the eastern platform abruptly terminates at a depth of about 11 feet below the low water level, where the lagoon floor flattens out to form the basin floor. The basin floor is smooth and gently slopes downwards towards the east, so that the deepest parts of the basin are at the foot of the marginal slope. Towards Youngusband Peninsula the basin floor rises gently to about six feet below the low water level, then rises more steeply to meet the western shelf. The greater part of the basin floor lies in excess of eight feet below low water

level, and about one half of it lies below the ten foot contour, (see Fig. 16). Near Trevarrow's Point, a reef of kunkar rock projects above the low water level and is surrounded by a belt of sand rising about four feet above the surrounding basin floor. This upraised area forms an isolated extension of the eastern platform.

Close to Wataleera Bay the central depression is constricted between outward projections of the two marginal platforms. A broad sill-like bank rising to about three feet above the adjacent basin floors extends across the constriction, marking the boundary between the Salt Creek and the Policeman's Point Basins.

(ii) The Policeman's Point Basin.

The Policeman's Point Basin is a group of interconnected circular and elongate depressions, partly divided by projections of the eastern platform. Away from the marginal slopes, the basin floor is smooth and almost horizontal, but the expanse of flat-lying floor is considerably limited by the confining platform areas. Most of the floor lies between 8 and 11 feet below the low water level. Tongues of sand extend across the basin, slightly above the general surface level, forming low ridges as shown in Cross-section E in Fig. 18 between C. 69 and C. 71.

West of Pelican Island, a trough shaped portion of the basin extends northward with decreasing depth, and becomes a clearly defined channel between the two platforms. This

constriction marks the separation of the Policeman's Point and the Cattle Island Basins. The channel affords the only deep water connection between the two basins. During the summer months the connection is about 1,000 feet wide and about six feet deep.

(iii) The Cattle Island Basin.

The floor of this basin is smooth and slopes gently downwards to the east. This basin is not as deep as the two previously described basins. At its deepest part it is slightly over six feet below low water level and most of the basin floor lies between 4 and 6 feet below low water level. A few small reefs of kunkar interrupt the smooth floor, projecting above the low water level. The central depression narrows to the west of Cattle Island, where the western platform extends to within 400 feet of the eastern platform, separating this basin from the Stony Well Basin to the north. The connecting channel between the two basins is about 400 feet wide and its floor lies about 6 feet below the low water level.

(iv) The Stony Well Basin.

The Stony Well Basin is a long shallow depression, clearly defined by a marginal platform on the southern and most of the eastern sides, but often poorly defined on the northern and western sides. The basin floor is smooth and slopes gently downwards to the east and to the south. Its deepest parts are in the south-eastern corner, where the basin floor lies about 6 feet below low water level, but

only about one quarter of the floor lies below the five foot contour, and most lies between the two foot and the five foot contours. A number of kunkar reefs and one large island project above the smooth basin floor. Most are surrounded by a slightly upraised belt of sand. The northern end is divided by the peninsula leading to Hack Point and a string of islands to the south. The eastern arm forms a cul-de-sac in which the lagoon floor slopes upwards to the north. West of Hack Point the western arm narrows abruptly to form a shallow channel flanked on either side by sand-flats. This constriction is regarded as the northern limit of the Stony Well Basin and of the Southern Lagoon. The lagoon immediately to the north is part of the Hell's Gate Passage.

2. Hydrology.

The area between Salt Creek Point and Hack Point shows the annual cycle of water level and compositional changes described previously. During winter the water level is about four feet higher than in summer. The chlorosity changes from values between 21‰ and 30‰ in winter to between 45‰ and 55‰ in summer.

During the period of high water level, the marginal shelf areas and the Hell's Gate Passage are covered by water a few feet deep, and the constricted areas do not have a great effect on the exchange of water between the various parts of the lagoon. A fairly uniform trend in water composition is maintained, with the chlorosity increasing

southwards along the whole length of the lagoon.

During the period of low water level, the maximum depth of water in ^{parts of} the Hell's Gate Passage is only a few inches, and the exchange of water between the Northern Lagoon and Southern Lagoon is practically eliminated. The Southern Lagoon behaves as if it were an isolated body of water, and in no way does it appear to reflect the presence of less concentrated water in the Northern Lagoon. The Southern Lagoon develops a pattern of chloride ion concentration controlled by its own topography, with a northward increase in concentration, the reverse of that shown at the same time in the Northern Lagoon, (see Fig. 15). At its southern end, the Bul Bul Basin becomes isolated from the other basin areas, and behaves as a third independent water body.

When the water level begins to rise in autumn, the effects of the constricted areas on water movement are progressively lessened and the lagoon again behaves as a single body of water.

Within the Southern Section, water movement is generally slow. Slow currents, moving at the rate of 10 or 20 feet per minute, have been observed just south of Hack Point at times of northerly winds, and in the inter-basin channels at times of low water level, when the wind induced water movements are confined to narrow channels. Very slow currents are indicated at times by the bowing of long fishing nets, or are revealed by the displacement of surface isochlor lines in maps showing the distribution of water composition -

see Fig. 15 .

3. Sediments.

Two broad groups of sediments are found in the lagoon between Salt Creek Point and Hack Point. These reflect the topographic differentiation of the lagoon into basin and platform areas in a fashion similar to that described for the Bul Bul Basin.

(a) Platforms and Lagoon Margins.

(1) Component Materials.

The sediments of the platforms and sand shelves are predominantly sand and shell deposits with a low mud content. In some shallow depressions within the platforms, muds form a thin cover above the normal coarse grained sediments.

Two components are recognisable in the coarse grained sediments - a detrital fraction, composed of quartz and calcareous grains, and a non-detrital fraction, composed of shell material derived from organisms which lived within the lagoon area.

Calcareous grains of detrital origin can be recognised in some cases by the degree of rounding, or by a comparison of their grain shape and size with the shape and size of fragments of the lagoonal fauna. The detrital grains are often better rounded than the fragments of the lagoonal shells, but in the fine and very fine sand-size classes, the degree of rounding is less distinctive. The combination of grain size, grain shape and the degree of rounding is such that many medium sand-sized and larger grains could not have

been derived from the shells of lagoonal organisms which possess highly curved and thinly walled shells. The presence of thick prismatic and lamellar crystalline layers in many grains indicates that they were derived from shells more robust than those which the lagoonal organisms possess. Tests of foraminifera, fragments of echinoid spines and other organic fragments foreign to the lagoonal fauna are found among the calcareous grains. In the fine sand-size class and finer material, these distinguishing characteristics are lost, and the proportion of indeterminate grains increases, so that it is not possible to determine the relative proportions of the two types of carbonate grains.

(11) Composition.

There is a wide variation in the composition of the platform sediments and changes are often abrupt or transitional over a short distance. The variation is principally a result of changes in the proportion of non-detrital shell material, but is partly a result of variation in the content of calcareous grains in the detrital fraction. The lack of criteria for distinguishing the detrital and non-detrital nature of some calcareous grains indicated that a detailed investigation of the compositional variations would be of limited value.

The content of total calcium carbonate in platform sediments is mostly between 20% and 40%, but extreme values are common. The calcium carbonate content exceeds 90% in some strandline concentrations of shell material and in some

shell accumulations on the outer parts of the platform areas or on the marginal slopes. At the other extreme, less than 5% calcium carbonate is contained by some fine grained sands in which detrital calcareous grains are absent and which contain only a few broken lagoonal shells.

Sands adjacent to the Recent dune drifts along the western side of the lagoon show a more uniform composition similar to that of the dune sands, with 40% to 50% calcareous grains. The calcareous grains are almost exclusively detrital and lagoonal shell material is very rarely found.

The calcareous grains of non-detrital origin are either calcite or aragonite, with the latter the more common, for most of the lagoonal organisms possess an araginitic test (see Table 17). Detrital calcareous grains are calcite, aragonite or mixtures of these two minerals. The non-calcareous detrital grains are predominantly quartz, with 1 or 2% microcline and potash-feldspar, and accessory ilmenite, hornblende, garnet, biotite and muscovite.

(iii) Grain Size and Sorting.

These two properties vary widely in response to changes in the proportions of the two component materials. Typical platform sediments show a wide range of grain sizes, with up to 10% silt and mud sized material, and generally more than 10% coarse sand or larger sized grains, (see Fig. 14). The mean grain size, the Graphic Mean " M_z " (Folk, in Folk and Ward, 1957), of most samples lies within the medium and fine sand-size classes, but in shell-rich

sediments it may lie in the coarse sand-size class (see Table 4). The sediments are most often poorly sorted (using the classification of Folk, based on the determination of his Inclusive Graphic Standard Deviation (σ_I)). Where the content of the non-detrital material is very low, the degree of sorting is greater and some samples are well sorted (see Table 4).

Most of the non-detrital grains are larger than 0.25 mm in grain size, but few of the detrital grains exceed this size; most of the detrital material is between 0.25 and 0.125 mm in grain size. The presence of a high proportion of each of the two components is responsible for the wide range of grain sizes and the low degree of sorting in average platform sediments. Changes in the proportions of the two components are responsible for the wide variation of the mean grain sizes and of the degree of sorting.

Sands along the western side of the lagoon adjacent to the Recent dune drifts show a restricted range of grain sizes and a higher degree of sorting, being at least moderately well sorted. In these respects they are similar to the detrital fraction of the platform sediments.

(iv) Grain Shape and Surface Texture.

The non-detrital fraction shows little evidence of abrasion over most of the platform areas. Complete and partly broken tests of the small Fauna 2 organisms form the greater part of the non-detrital material in most areas. Fragments larger than 0.25 mm in size are strongly curved,

reflecting the shape of the original organism and show sharply broken edges. Smaller fragments are more equant, with angular or subangular edges. Only in the strandline deposits along the high water level is there significant rounding of the grains; here most of the grains are rounded to subrounded. Fragments of large lamellibranch tests are tabular and may have subrounded to subangular edges. The small fragments of these larger species are equant, with subangular to angular edges.

In the detrital fraction, the calcareous grains are tabular and rounded to well rounded when of medium sand-size or larger, but become equant and subangular in the finer size classes. Quartz grains are mostly subrounded, with some rounded and well rounded grains in the coarser fractions. The degree of rounding decreases with decreasing grain size to subangular to angular in the fine and very fine sand-size classes.

Calcareous grains show two types of surface texture. One type is characterized by a clean natural appearance, with smooth shining surfaces along broken faces and on parts of the exterior surfaces. This texture, similar to that shown by fresh shell material, is commonly found on tests and fragments of Coxiella confusa, Disphoromastrea versicolor and Ammonia beccarii, but is rare on most other calcareous grains. The second type is characterized by a dull chalky appearance, often accompanied by small scale pitting and frosting. Such grains appear to be smoothed and worn, but

the presence of thin and angular corners and edges indicates that a mechanical origin is unlikely. It is most likely that this surface texture has been formed by corrosion through either chemical or biochemical processes. This surface texture is common on the shells of the three species listed on page 115 and they show gradational stages in its development. It is the most common texture on shells and fragments of the older Fauna 1 remains and on the calcareous grains derived from the Pleistocene dunes. Those derived from the Recent dunes have polished surfaces, bearing a light, scattered frosting.

Two varieties of quartz grains can be recognised, mainly on the basis of the texture shown by the grain surfaces. One variety shows fairly smooth, glassy faces with minor re-entrant areas. This is similar to the texture shown by the quartz grains of the Recent dunes and by most of those of the unweathered Pleistocene aeolianites. Those of the second variety have a more irregular outline, although many of the corners and edges may be rounded. The surface is pitted and of rough appearance, with relatively deep re-entrant areas producing the irregular grain outlines. Frosting may be present, and as this extends into deeply recessed areas, it is unlikely to have been caused by mechanical means. This fact and the irregular grain shapes suggest that the grains which are of rough appearance have been subjected to some form of corrosion. Quartz grains with a similar appearance are found abundantly in the weathered zone within the

Pleistocene aeolianite, and less commonly in the unweathered aeolianite, where they appear to be due to corrosion of quartz grains by the calcitic matrix. Between 50% and 75% of quartz grains on the platform areas are of the irregular variety in areas away from the Recent dunes of the western side, suggesting that the platform sands are largely derived from weathered Pleistocene aeolianite.

(v) Sedimentary Structures.

Platform sediments generally lack clearly defined sedimentary structures, but poorly defined stratification is indicated in a few cores by shelly or slightly muddy horizons. Horizontal orientation of larger shells or fragments is common. Stratification is commonly developed in strandline deposits, where a well developed lamination is outlined by variations in grain size and shell content of adjacent laminae. Low beach ridges along the strandline sometimes show medium-scale cross-bedding. The sediments exposed during the period of low water level are moderately compacted and a moderately firm crust develops at the surface as the sand dries. The development of ripple marks on this surface is very rare and confined to the immediate vicinity of the high water level.

(b) The Central Depression.

The low lying basin areas are partly filled by a sequence of fine grained mud and light organic detritus. The sequence was shown by probing to exceed 11 feet in thickness in the Salt Creek Basin, but the deepest material

collected was at a depth of nearly 9 feet in the Stony Well Basin. The maximum thickness of the sequence in the central parts of the basins is not known, for most of the cores penetrated only the uppermost 5 feet of the sequence.

(1) Colour and Eh.

Surface muds are black or dark grey when freshly collected. Eh measurements of surface and near-surface muds from a few localities showed values between -0.30 and -0.35 volts. There is a smell of hydrogen sulphide from freshly cut cores, and from the lagoon at times when the muds are stirred by wind action. Below a depth of a few inches, the colour varies from medium or pale grey to green-brown, in part reflecting compositional changes. After treatment with hydrogen peroxide, the colour of completely oxidised samples reflects compositional changes more closely. Surface and subsurface muds from the Salt Creek Basin are white or very pale grey after oxidation in hydrogen peroxide, reflecting a high content of calcareous mud. Below a depth of three to four feet in the sequence, the oxidised muds are pale grey to grey-brown, reflecting a higher content of argillaceous material. Further to the north the thickness of mud showing very pale colours decreases and in the Cattle Island and Stony Well Basins, even the surface muds are grey after oxidation. This parallels the northward decrease in the calcareous content of surface muds described on page 120.

(11) Texture.

Granular muds are most commonly found in the Policeman's Point and Salt Creek Basins, where finely granular muds, in which the aggregates are 0.05 to 0.10 mm in diameter and often diffusely defined, predominate in the topmost 3 or 4 feet of the sequence. The lower part of the sequence shows more homogeneous mud than granular mud. In the Cattle Island Basin both these textures are common, but in the Stony Well Basin the muds are mostly homogeneous.

Ovoid pellets about 0.25 mm long and 0.1 mm thick are found in all four basins. They occur scattered through beds of granular mud, or in beds which are largely or completely pelletized. The surface layer over a large portion of the Salt Creek Basin consists of pelletal mud (see Fig. 18). Sub-surface beds of pelletal mud occur in most cores, and in some cases individual beds may be correlated between a number of cores, (see Fig. 18).

(111) Sedimentary Structures.

Stratification is well developed in this part of the lagoon, although the larger scale bedding is not as obvious as in the Bul Bul Basin. Bedding is mainly outlined by changes in mud texture. Sharply defined microcoquina layers also outline bedding, particularly in the lower parts of the sequence.

Lamination is very well developed in the Salt Creek and Policeman's Basins, where a few horizons of thinly laminated mud occur in most cores. The lamination is outlined by

textural variations or the alignment of ostracod tests and disseminated algal fibres. Some of the laminated beds are laterally persistent (see Fig. 18), and one prominent horizon probably extends through the Salt Creek Basin into the Policeman's Point Basin as far as core O.78.

No clearly defined rhythmic or cyclic sequence of sediment types and textures were observed. Ostracod laminae with sharply defined basal contacts and gradational upper surfaces are common, and some granular muds grade upwards into homogeneous muds, but there is no clear indication of the sequence shown in the Bul Bul Basin.

In a few localities along the western margin of the Salt Creek Basin, encroaching dune sands have deformed the lagoonal muds, forming a series of mud-folds, which will be discussed on page 176.

(iv) Composition.

The composition of mud sediments from the Central depression is summarized in Tables 7-13. These determinations were carried out on material which passed through a 240 mesh (B.S.S.) sieve (aperture size 0.066 mm).

Total calcium carbonate content.

The surface muds are highly calcareous, but they show a northward decrease in the calcium carbonate content, continuing a trend which commences in the Ephemeral Lagoon (see Table 2). The proportion of calcium carbonate falls progressively from above 60% near Salt Creek Point to slightly less than 50% near Stony Well Island.

Below the sediment surface, the calcium carbonate content fluctuates, but shows at least one sharply defined decrease in most cores. In the Salt Creek Basin the carbonate content fluctuates between 58% and 72% down to a depth of about 52 inches. At this level, the percentage decreases by over 10% in close or adjoining intervals, and in lower intervals the values fluctuate between 37% and 51%. There is a less pronounced decrease from values above 50% to less than 43% in the Policeman's Point Basin, but here the change is found closer to the sediment surface, at depths of about 24 to 30 inches. In the Cattle Island and the Stony Well Basins, the higher surface values show even less vertical persistence. Below the uppermost few inches the percentage decreases abruptly to less than 40%, then continues to decrease downwards, with some fluctuation. In the Stony Well Basin, the carbonate content maintains a fairly constant value between 16% and 22% in the lower part of the sequence. This lower limit is reached at about 50 inches below the surface in cores south of Stony Well Island, and at about 25 inches below the surface north of the island. Two subsurface samples from core C.99 near Hack Point contained no detectable calcium carbonate, see Table 13.

Mineralogy.

The non-calcareous portion of the mud fraction consists of two clay minerals, one belonging to the chlorite group, the other to the mica group, and a little silt-sized quartz.

The calcareous portion consists of either magnesian calcite and aragonite or magnesian calcite alone. In all surface samples both minerals are present, and the relative intensities of X-ray patterns of the two minerals indicate that aragonite is the more abundant. Below the sediment surface, the relative proportions of the two minerals remains fairly constant, with the ratio of intensities of the aragonite and calcite patterns between 2:1 and 3:1, down to a depth at which there is a marked change. At this level the relative proportion of aragonite decreases abruptly over an interval of up to 15 inches thick, (see Fig. 9 and Tables 7-13). In samples from below this transitional interval, aragonite leaves only a trace on the X-ray patterns or may be completely absent.

This mineralogical change occurs within a few inches of the level at which the total carbonate content shows a marked change. Thus, the mud sequence can be divided into two parts. In the higher part of the sequence, aragonite is the dominant mineral in the carbonate fraction of the mud. The muds are moderately to highly calcareous, containing above 50% calcium carbonate, except in the northern-most part of this section of the lagoon. In the lower part of the sequence, the calcareous component of the muds is predominantly composed of magnesian calcite. The muds in this part of the sequence have a markedly lower carbonate content, being moderately to slightly calcareous. The thickness of the aragonite-rich part of the sequence

decreases from about 5 feet near Salt Creek Point to less than 1 foot near Hack Point.

The average magnesium content of the calcite in surface muds of the Salt Creek Basin (7.0 mol % MgCO_3) does not differ significantly from the average surface values of the Bul Bul Basin or the Ephemeral Lagoon (see Table 2). The average surface values of the remaining basins are lower, but the accuracy of the determinations is such that no statistical significance can be given to the differences between adjacent basins. The difference between the average values for the Salt Creek and Stony Well Basins is statistically significant and suggests that there may be a slight northward decrease in the magnesium content of surface calcite between Salt Creek Point and Hack Point.

In subsurface samples down to a depth of about 10 to 20 inches the calcite shows a magnesium content close to that of the surface samples. Below this depth there is a pronounced increase in the magnesium content of calcite. In the Salt Creek and Policeman's Point Basins, the magnesium content increases to between 10 and 16 mol %, and remains in this range through the known sequence. This is similar to the pattern found in the Bul Bul Basin. In the Cattle Island and Stony Well Basins, the subsurface increase is less marked and less consistently shown. The magnesium content increases to between 8 and 13 mol %, but these higher values are only shown over an interval of about 30 inches,

below which the values are close to those of the surface samples.

4. Organic Remains.

(1) Plant remains.

Algal fibres, small plant stems and eogonia of Chara are rare to abundant in the sediments of the central depression. They are rarely preserved in the sediments of the platform areas. Small calcareous tubes up to 6 mm long and 0.8 mm in external diameter are rare in many intervals of the mud sequence and form a large proportion of the coarse fraction in washed samples in a few intervals. They have a thin wall of calcite about 0.05 mm thick. This has a smooth interior and a granular exterior, covered by small lumps up to 0.05 mm in diameter. In two instances, the interior of tubes was occupied by plant material suggesting that the tubes formed as encrustations around plant stems or algal fibres. Concentrations of the tubes were often associated with concentrations of eogonia of Chara, so that it is possible that the tubes were formed around stems of that plant.

(11) Diatoms.

Small disc-shaped diatom valves, possibly belonging to a single species, are found in the sediments of the central depression. They are rare in the Bul Bul Basin sequence and in most surface and near surface muds of the main basins. Below a depth of 2 to 3 feet they are far more numerous, often forming a large proportion of the coarse fraction in

washed samples.

(iii) Bryozoa.

Fragmented bryozoan colonies are a rare accessory throughout the mud sequence. They are common in parts of the platform areas and in some laminae of microcoquina in the central depression. The fragments are usually in the form of thin sheets and chains a few mm across, which have probably been derived from the large colonies found encrusting rocks in the platform areas, (see page 153). A few thin tubular colonies with dimensions similar to those of the calcareous tubes described above, have probably formed as encrustations around plant stems.

(iv) Ostracods.

Ostracod tests are numerous in the sediments of the central depression, but are generally rare in the sand and shell deposits of the marginal areas. The number of species present is small, but they show an important distribution pattern within the central depression.

The most numerous ostracod species has bean-shaped valves about 0.5 mm long and 0.3 mm wide, (see Plate 18). The valves are usually clear but are occasionally milky. The hinge is simple and lacks teeth. The nature of the muscle scars and the hinge line indicate that this species belongs to the Family Cypridae. Ludbrook (1956) described a similar ostracod from the Pleistocene to Recent deposits at Lake Eyre in South Australia, and identified it as Pontocypris attenuata (Brady). As it is uncertain whether

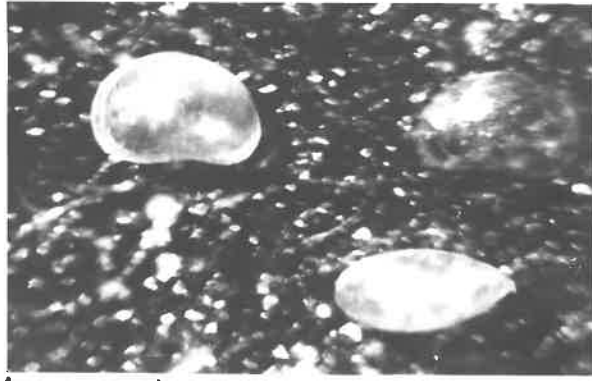
PLATE 18.

Ostracod Species A, B and C, left and right valves
and dorsal view.

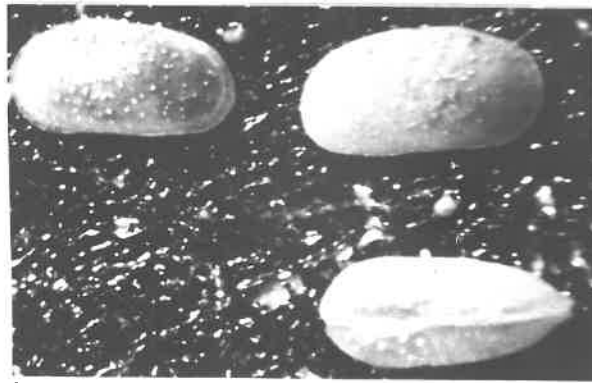
SPECIES A.

SPECIES B.

SPECIES C.



0.5 mm



1 mm



1 mm

this Coorong ostracod belongs to that species, it has been designated as "Species A" in this discussion.

A larger member of the same family is found associated with Species A. Tests of this species are translucent to milky. They are elongated and possess an acutely angled posterior. This ostracod possibly belongs to the genus Paracypris (Sars). Specimens range up to 2 mm long and 1 mm wide. They are extremely fragile and are mostly found fragmented. This species is common in most samples containing Species A, but never forms more than about 5% of the ostracod remains in washed samples. Tests of at least one other unidentified cyprid species are rarely found associated with Species A.

Two other ostracod species are moderately common in the sediments of the central depression and the platform areas. Tests of both show a vertical row of four muscle scars, with two others towards the anterior end, and both belong to the Family Cytheridae. As further classification was uncertain, the two varieties have been designated as "Species B" and "Species C".

Species B. (See Plate 18).

These tests are semi-transparent and white.

They are oval-shaped and up to 1 mm long, 0.5 mm wide and 0.5 mm thick. The outer surface is smooth and finely punctate. The hinge is slightly curved and complex.

Species C. (See Plate 18).

The tests of this species are generally translucent and white, but are rarely opaque or colourless and transparent. They are oblong, with a rounded outline, and of the same size as those of Species B. The outer surface bears an irregular pattern of polygons, outlined by narrow ridges. The hinge line of the right hand valve is straight and is composed of two narrow, crenulated teeth, separated by a finely crenulated shallow groove. The hinge line of the left hand valve is complementary.

Tests of Species A occur in all surface and near surface samples in the central depression, often constituting over 90% of the coarse fraction in washed samples. This abundance is maintained down through the sequence, except in the few shelly and sandy laminae, to a depth of 2 or 3 feet below the surface. Here, their abundance decreases, and they form only a minor portion of the coarse fraction over a short interval, then virtually disappear from the sequence. Paracypris (?) sp. and Species B show a similar vertical distribution, (see Fig. 19), but both are relatively rare.

Tests of Species C are generally absent over most of the range of the above species; in a few surface and near surface samples one or two valves are found. Towards the bottom of the Species A range, tests of Species C are found to be rare in most washed samples. In the known part of the

sequence below the range of Species A, tests of Species C are found in most intervals examined. They generally vary from very rare to abundant but are absent in a few intervals. They do not attain the abundance shown by Species A in the overlying sediments, and never form more than about 5% of the coarse fraction of washed samples. In spite of their comparative rarity and their occasional absence, this species shows a recognizable vertical range in the sequence of the central depression. This range only partly overlaps the range shown by Species A, and extends below the latter to the deepest known parts of the sequence.

(v) Foraminifera.

Unidentified Niliolid and Elphidium species are found in most samples from the platform areas and the central depression, but they are generally very rare. The most abundant foraminifera is Ammonia beccarii, which is found in both platform and central depression sediments. It forms a major proportion of microcoquina beds in both environments. Within the central depression, tests of this organism are generally rare in the topmost sediments, but become abundant in the lowermost parts of the sequence. Here many thin laminae and pods may be composed entirely of these tests. The level at which A. beccarii shows an increase in abundance is usually within a few inches of the interval in which the ostracod fauna shows the change described above, (see Fig. 19).

(vi) Mollusca.

The two groups of mollusca outlined in the discussion of the Ephemeral Lagoon and the Bul Bul Basin are found in the sediments of the main basin areas. The larger lamelli-branches are mainly confined to the platform areas and to sand and shell deposits which interfinger with or underlie the mud sequence of the central depression. Flavomala donacoides is found in mud beds within the lower parts of some cores. Most of the molluscan remains of the central depression consist of shells of Coxiella confusa and Diaphoromactra versicolor. These are generally rare in the uppermost parts of the sequence, but show an increase of abundance in the lower parts of the sequence, where they form many microcoquina laminae. Over parts of the platform areas, they form beds of microcoquina, containing a high proportion of A. bessarii tests. They are generally absent below a depth of about a foot from the platform surface.

(vii) Distribution.

As mentioned previously, the molluscan remains have been used as the chief criterion for dividing the organic remains of the lagoonal sediments into two assemblages. This division has an important bearing on the interpretation of the history of the lagoon.

Fauna 1.

Fauna 1 is characterized by relatively large lamelli-branches (see Table 1), with the most abundant being Flavomala donacoides, Notospisula trigonella and Katylepis

sp. The members of this group are marine organisms found alive along parts of the South Australian coastline. According to Gotton (1961), these species are found within or slightly below the intertidal range in relatively sheltered marine and estuarine sand or mud flats. Living F. donacoides and N. trigonella have been observed in a few localities in the Northern Lagoon. The remaining species are probably extinct throughout the lagoon, whilst in the Southern Lagoon all are extinct. Their tests are occasionally found in the position of growth in the platform sands and tests of Venerupis sp. have been observed in situ in small cavities within the soft aeolianites along the eastern shoreline.

Fauna 2.

Fauna 2 is characterized by sub-microscopic and microscopic remains of the mollusca G. confusa and D. versicolor, the foraminifera A. beccarii, and the ostracods described previously. The three species named above are known to be euryhaline and to flourish in marginal marine environments which show brackish or hypersaline conditions. A. beccarii is found, but less abundantly, in sediments containing only members of Fauna 1, and it is the presence of this organism in abundance which characterizes Fauna 2.

Members of the two faunas are found intermixed over most of the platform surface, but Fauna 2 is confined to the topmost foot or so in most places. In the outer parts of the platform and on the marginal slope, accumulations

composed almost entirely of Fauna 2 tests form a cover a few inches thick above sands containing both faunas. These may be in turn underlain by sands containing only Fauna 1. In the central depression the mud sequence is characterized by Fauna 2. Where the base of the sequence has been penetrated, the underlying shell beds may show a downward gradation from Fauna 2 to Fauna 1.

This relationship between the two faunas indicates that Fauna 1 characterizes an earlier phase of deposition within the lagoon than that characterized by Fauna 2. On the platform areas, the sediments of the earlier phase have only been partly covered by later deposits, and remains of Fauna 1 are therefore widespread in the surface sediments. This suggests that the rate of sediment accumulation over most of the platform areas has been very low since the extinction of Fauna 1. In the central depression, sediments of the earlier phase of deposition have been covered by a thick cover of mud, characterized by the presence of Fauna 2 alone.

Within the sediment sequence of the central depression, the organisms of Fauna 2 show a stratigraphic division into two parts. The chief basis of this separation is the variation in the vertical distribution of ostracod species as described on page 127. Other organisms show a change in abundance close to the change of the ostracod fauna. The changes which lead to this differentiation seldom coincide, so that the change is regarded as occurring over an interval

of transition which may be up to 20 inches thick. The two groups are designated as "Faunule A" and "Faunule B".

Faunule A.

The upper Faunule, Faunule A, is characterized by an abundance of the ostracod Species A, with lesser numbers of Species B and Paracypris (?) sp. C. confusa, D. versicolor and A. beccarii are widespread but generally rare.

Associated with this faunule, algal fibres are abundant in some samples. Diatoms are generally very rare, and seldom form a large part of the coarse fraction of washed samples.

Faunule B.

The lower assemblage, Faunule B, is characterized by the presence of the ostracod Species C and the virtual absence of Species A and associated species. C. confusa, D. versicolor, and A. beccarii are abundant, being dominant in the coarse fraction of most washed samples. Over the range of this faunule, diatoms are often abundant, and sometimes form the greater part of the coarse fraction. Algal fibres are generally rare in the range of this faunule.

In the Bul Bul Basin, the cores have penetrated the top of the faunal transition, but do not appear to have revealed the full extent of the interval. In the basins to the north, the transitional interval is found slightly closer to the surface, (see Fig. 9), occurring between 2 and 4 feet below the surface. In two cores the depth of the interval is anomalous (cores C.65 and C.83). Both are located close to inter-basin channels, and may therefore have been collected

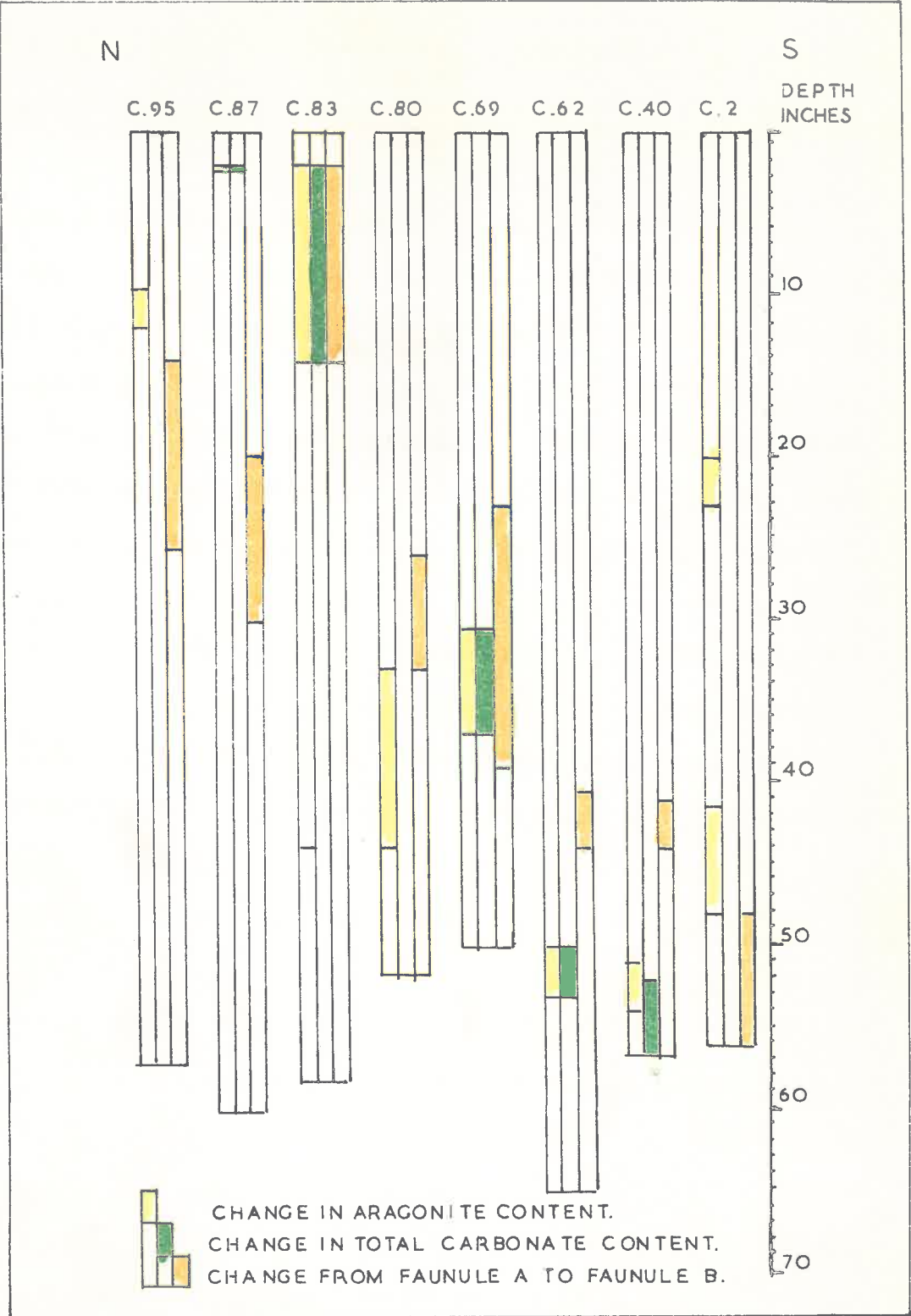


Figure 9.

The distribution of the main mineralogical and faunal changes in the central depression of the Southern Lagoon.

from localities in which the depositional rate differed from that in the remainder of the depression from time to time.

There is no strict coincidence between the interval of the faunal transition and changes in mud composition described previously, (see Fig. 9). In the Bul Bul Basin and Salt Creek Basins, the faunal transition is located well below the level at which the compositional changes take place. In the Policeman's Point and Cattle Island Basins the two levels coincide, but in the Stony Well Basin the compositional changes are found above the faunal change.

(D) SUMMARY.

The Southern Lagoon is that half of the Coorong Lagoon which is most removed from the mouth of the River Murray, the lagoon's only connection to the Southern Ocean. It is separated from the Northern Lagoon by the shallow confines of the Hell's Gate Passage, which greatly restrict the circulation of water along the length of the lagoon. This restriction has greatly reduced the ability of either sea or river waters to moderate the highly hypersaline conditions generated by evaporation during each summer. As a result, the waters of the Southern Lagoon remain hypersaline throughout the year.

The waters of the Southern Lagoon show a marked annual cycle in changes of physical and chemical properties. The winter conditions are characterized by a relatively high water level, which allows a moderate degree of water circulation along the length of the lagoon. Dilution of the waters of the Southern Lagoon by sea, rain and river waters produces slightly hypersaline conditions, with chlorosities between 22‰ and 30‰. Water temperatures are between 9°C and 14°C. Summer conditions are characterized by a water level which is about 4 feet lower than in winter. This greatly reduces longitudinal water circulation and virtually isolates the Southern Lagoon from the Northern Lagoon. Water temperatures are high (20°C to 25°C), and the waters become highly hypersaline, with chlorosities about 55‰.

The Southern Lagoon shows a number of depositional environments in which the topography of the lagoon floor has been the main factor controlling differences in the nature of sediments deposited. The southernmost portion of the Southern Lagoon is the Ephemeral Lagoon, an elongate area subjected to alternating long periods of inundation and emergence. At the present time, sedimentation is largely confined to the marginal and extremal portions, where sandy muds are being deposited. The muds are predominantly a mixture of aragonite and magnesian calcite, with aragonite the more abundant. These deposits form a thin veneer above shell-bearing sands which extend into the central portion of the Ephemeral Lagoon, forming the surface sediments there. The fauna of these sands indicates that they were largely deposited during an earlier depositional phase under more normal marine conditions. This area is now an area of very slow or no deposition.

At its northern end, the Ephemeral Lagoon grades into the main part of the Southern Lagoon. This consists of a series of permanently inundated basin-like depressions bordered by higher platform areas, large parts of which are periodically exposed by the annual fall of water level. All but the southernmost of the basins are interconnected by permanent passages of water up to 9 feet deep at times of low water level.

The topography of this part of the lagoon floor has been controlled by Pleistocene dunes which were present in

the area at the time when the lagoon first formed. Dunes within the submerged area have been extensively truncated close to the water level and the eroded remnants have formed the framework within which lagoonal sediments have been deposited. Sands deposited around the dune remnants have formed a broad platform bordering a central depression. More recently, sedimentation over the platform areas has been confined to the deposition of a relatively thin and discontinuous cover of lagoonal shell material. Along parts of the western side of the lagoon, Recent sand dunes are moving into the lagoon and are being eroded by the lagoon waters. The reworked dune sands are being deposited as sand shelves extending across older platform sediments and, in some cases, across the lagoonal muds of the central depression.

The central depression of the Southern Lagoon forms the main site of lagoonal sedimentation under the present environmental conditions. The basin areas contain a sequence, several feet in thickness, of muds interbedded with thin beds of microcoquina and concentrated algal and ostracod remains. As this sequence accumulated it progressively overlapped the marginal slopes of the platforms. In the Bul Bul, Stony Well and Cattle Island Basins, the mud sequence has largely filled the central depression and is spreading across parts of the platform areas. In the Policeman's Point and Salt Creek Basins, the steep marginal slopes of the central depression are still largely

uncovered, and there is a sharply defined differentiation of the platform and central depression areas.

The sediment sequence of the central depression generally shows a moderately well developed stratification, outlined by textural changes in the mud beds or by interbedded layers of concentrated organic remains. In the Salt Creek and Policeman's Point Basins beds of laminated mud are common, whilst in the Bul Bul Basin beds of laminated algal fibre are a common feature. Much of the mud shows some form of aggregation. Beds of pellets and less regularly shaped granular aggregates form the greater part of the sequence down to a depth of 3 or 4 feet below the surface.

There are three important compositional changes in the mud sequence:

(1) Total carbonate content.

The surface muds are highly calcareous over most of the Southern Lagoon. The carbonate content increases from a little below 50% near Hack Point to above 80% at the southernmost end of the Ephemeral Lagoon. Below the surface, the carbonate content of the mud fluctuates, but in the four basins north of Salt Creek Point there is a definite subsurface interval in which the carbonate content decreases suddenly by 10 to 20%. The depth at which this change takes place decreases from about 4 feet below the surface in the Salt Creek Basin to within the topmost one foot in the Stony Well Basin. The carbonate content generally falls to between 30% and 50% below the level of the pronounced

TABLE 2.

Average d(112) spacings of calcite and average total carbonate (as CaCO_3) in surface muds of the Southern Lagoon.

Location	Average d(112) (Å)	mol % MgCO_3	Total Carbonate %
Ephemeral Lagoon.	3.019	6	88
Bul Bul Basin.	3.015	7	73
Salt Creek Basin.	3.016	7	59
Policeman's Point Basin.	3.022	5	55
Cattle Island Basin.	3.027	3	52
Stony Well Basin.	3.026	4	45

change. In the Stony Well Basin there is a further decline to values between 16% and 22% at depths of 2 to 4 feet below the surface.

(ii) Carbonate mineralogy.

The second compositional change involves a change in the mineralogy of the calcareous component. This change generally occurs close to or coincides with the pronounced change in total carbonate content. In the uppermost muds aragonite is more abundant than magnesian calcite. Lower in the sequence the aragonite content shows a sudden decrease over a short interval. Below this level, aragonite is present in only small quantities or is completely absent, and magnesian calcite becomes the predominant calcareous mineral present.

(iii) Magnesium content of calcite.

The third compositional change involves the magnesium content of the calcite. Although there is a suggestion of a northward increase in this value in the surface muds of main basin areas, the accuracy of determination of the d(112) spacings is relatively low. Average values along the whole of the Southern Lagoon (see Table 2) show that it is more likely that the magnesium content of surface calcite is uniform throughout. Sub-surface samples below a depth of 10 to 20 inches show a marked increase to values two to three times those in the overlying muds. However, in the Stony Well and Cattle Island Basins, the higher values are shown only over intervals of about 30 inches, below which

the magnesium content reverts to values close to those of the surface.

The organic remains of the Southern Lagoon form two distinct groups, of different ages and characterizing different depositional environments. The younger of these groups can be subdivided into two parts.

Fauna 1.

Fauna 1, the older group is characterized by an assemblage of moderately large lamellibranchs, members of which are indicative of a sheltered marine environment which prevailed during an early stage in the development of the lagoon.

Fauna 2.

Fauna 2, the younger group, is characterized by smaller organisms which are euryhaline. Their presence records the development of a wider seasonal variation in water composition within the lagoon. In the sediments of the central depression this group can be subdivided into two faunules.

Faunule B.

The lower faunule in the sequence, Faunule B, is characterized by the presence of a cytherid ostracod, Species C, and an abundance of Coxiella confusa, Diaphoromactra versicolor, and Ammonia beccarii. Diatoms are abundantly associated with the members of this faunule.

Faunule A.

Overlying Faunule B in the sequence of the central

depression in Faunule A. This is characterized by an abundance of an unidentified cyprid ostracod, Species A, and two less common species. C. confusa, D. versicolor and A. beccarii are members of this faunule, but are less abundant than in Faunule B. Diatoms are rarely present in association with Faunule A.

Faunule A is characteristic of the present conditions in the Southern Lagoon, whereas Faunule B is indicative of conditions similar to those of the Northern Lagoon, as will be discussed in a later section.

1. Margin Outlines.

Between Hack Point and Needle's Island, the Pleistocene dunes of the mainland form two projections of land, up to 50 feet above the lagoon level, which extend towards Young-husband Peninsula. The two peninsulas and a few small islands restrict the lagoon to a narrow passage of irregular outline (see Fig. 17). At its narrowest point, near Hell's Gate, the low lying area between the two dune systems is only 500 feet wide. The lagoon there forms a channel 350 to 400 feet wide, bordered by low lying swampy areas.

2. Topography of the lagoon floor.

In the Hell's Gate Passage, the lagoon floor is mostly a sand-flat lying close to the low water level, and much of it is slightly above that level. A few low islands of kunkar and Samphire-covered mud rise above the high water level. A continuous channel between 250 feet and 800 feet wide extends from Hack Point to Bluff Island. Near Hell's Gate, and at two other localities between there and Hack Point, the flow of water has been greatly confined by rock outcrops, and the channel floor is up to 10 feet below the low water level. But these depressions are exceptional, and the channel is generally less well defined, with its floor only about one foot below the adjacent sand-flat, (see Fig. 16). In one section slightly north of Hack Point, the

complete width of the channel lies only a few inches below the low water level, so that the continuity of the lagoon is almost severed during periods of low water level.

North of Bluff Island the channel disappears as the lagoon widens for a short distance. This area was not investigated, but aerial photographs show that the lagoon floor is at a shallow depth. In the vicinity of Needle's Island, the lagoon is again constricted and becomes very shallow. To the east, south and south-west of the island, the lagoon floor lies a few inches below the low water level across the complete width of the lagoon. This area and the shallow area near Hack Point practically stop the flow of water through the passage during the period of low water level, and are the principal barriers to the exchange of water between the Northern Lagoon and the Southern Lagoon at such times.

3. Hydrology.

During the period of high water level, the passage is filled to a general depth of four or five feet, with greater depths in the more deeply scoured parts of the channel. Water flows back and forth under the influence of winds and the rate of flow is relatively high, particularly through the more restricted parts. Exchange of water between the two principal sections of the lagoon may lead to similar water compositions in the areas immediately to the north and south of the passage. Some limitation is imposed by the

passage for it has been observed to separate waters of different compositions on some occasions during the period of high water level, (see Fig. 15). Because of its length and relative narrowness, the passage probably acts as a partial barrier to the southward movement of less saline waters when the lagoon is full or nearly full.

When the lagoon water level falls, the effectiveness of the connection through the passage decreases, and the Southern Lagoon becomes progressively more independent of the Northern Lagoon, until a virtual separation develops.

4. Sediments.

The portion of the passage immediately to the north of Hack Point is occupied by a sequence of at least 5 feet of interbedded shell, shelly muds and muds, which extend northwards from the Stony Well Basin to near the locality of core C.101. North of this point, the passage sediments are sand and shell mixtures, with a little interbedded mud. A sequence of at least 5 feet of dark grey and black muds is found in the channel near Hell's Gate. These sediments were not analysed, but appear to be similar to those shown in the Northern Lagoon and in core C.100 near Hack Point. The shell material is predominantly a mixture of Coxiella confusa, Diaphoromactra versicolor and Ammonia beccarii tests, with some scattered tests of the large lamellibranchs of Fauna 1.

III

THE NORTHERN LAGOON.

The Northern Lagoon was not examined in detail, but sufficient sediment and water samples were collected to show the general outline of the sediments and the depositional environment of this area.

1. Margin Outlines.

Much of the Northern Lagoon is only about one half as wide as most of the Southern Lagoon. The western shoreline is similar to that of the section between Wataleera Bay and Bul Bul seep, with Recent dunes of Youngusband Peninsula bordering the lagoon along the whole of this side. North of the point across the lagoon from the Seven Mile, extensive dune drifts reach the lagoon along most of the shoreline.

The eastern shoreline is similar in appearance to that of the Southern Lagoon, with stretches of cliffs cut into the Pleistocene dunes, separated by some low-lying areas where low mounds and dunes of lagoonal sand border the lagoon. The cliffs differ slightly from those in the south, for there is little development of scree slopes at the base of the cliffs, (see Plate 12). The cliff sections show that the Pleistocene dunes are here less weathered, for they show a relatively thin kunkar profile above unweathered aeolianite. The aeolianite is moderately indurated, and is therefore less easily eroded and more able to maintain a steep face without slumping than the weathered aeolianites

in the south. The capacity of the lagoon waters to remove and redistribute the material eroded from the dunes is evidently sufficient to keep pace with the rate of supply, and so maintain a steep cliff profile.

2. Topography of the Lagoon Floor.

A clearly defined sand platform extends out from the eastern shoreline, with a moderately flat surface, ranging from slightly above the low water level to three or four feet below that level. Unlike the platform of the Southern Lagoon, it does not show remnants of eroded kunkar outcrops, but it is traversed by linear biohermal structures, composed of serpulid worm tubes. These structures show arcuate and sinuous patterns similar to those of the kunkar outcrops on the platforms of the Southern Lagoon. The lines of the bioherms do not extend right up to the shoreline, but at their landward ends they are aligned with kunkar profiles in the cliff face, (see Plate 22). The foundation of the main serpulid masses could not be determined. However, their configuration and the spatial relationships with the adjacent kunkar profiles in the cliff line indicate that their localisation has been controlled by outcrops of kunkar which once extended onto the platform. These are now completely covered by serpulid tubes, and are possibly below the adjacent platform surface.

The outer limits of the platform are marked by a clearly defined marginal slope, over which the lagoon floor descends

to a depth of 6 to 9 feet below the low water level. At the foot of the marginal slope, there is a central depression similar to that of the Southern Lagoon. The greatest depth recorded was 9 feet below low water level, but in the region south of Boundary Bluff the lagoon floor does not exceed seven feet below low water level. The floor of the depression slopes gently upwards to the west, and near the western shoreline, the slope steepens to varying degrees.

3. Hydrology.

The waters of the Northern Lagoon show an annual cyclic change of compositions ranging from brackish to hypersaline, (see Fig. 5). During the period of high water level, part or all of this section of the lagoon shows brackish conditions, for fresh waters from the River Murray dilute the marine and hypersaline waters found at other times. With the cessation of strong river flow during the summer months, the lagoon is again in contact with the ocean waters, and normal marine conditions may be found throughout the section for a short period. Later, evaporation leads to the development of hypersaline conditions at the southern end of the Northern Lagoon, but normal marine compositions are maintained at the northern end by tidal movements. Slight variations in water level observed in the Seven Mile region are probably caused by wind induced movements rather than tidal oscillations. The absence of significant tidal influence at the southern end and restrictions on longitudinal water

circulation imposed by the narrowness of the lagoon allow the development of hypersaline compositions as evaporation proceeds. Outflow from the Southern Lagoon during the spring and early summer months probably contributes to the increase in salinity, at least in the Seven Mile area.

4. Sediments.

(a) Eastern Platform.

The sediments of the platform area in the Northern Lagoon have a more uniform composition and grain size distribution than those in the Southern Lagoon. Microscopic examination of samples from the Seven Mile and Pelican Point areas, and size analyses of four of these, show that the platform sediments are well sorted and moderately well sorted sands, predominantly of fine sand size (see Fig. 14 and Table 4).

The sands are highly siliceous, generally with only 1 or 2%, or rarely up to about 20%, calcareous grains, mainly as coarse angular shell fragments. The quartz grains in the modal class are sub-angular, but those in the coarse and very coarse size fractions, which constitute only 1 or 2% of the whole, are rounded or well rounded. The grains are of regular appearance and are equant in shape. They have slightly frosted surfaces.

(b) Central Depression.

The central depression shows a succession of dark coloured muds with interbedded layers of micrococquina and

shelly sand. They were cored to a depth of nearly 5 feet without reaching the base. The muds are black down to a depth of about 7 inches, below which they are dark grey or greeny grey.

Most of the mud shows a homogeneous texture, but thin bands of pelletal mud were found in some cores, mainly close to the surface. The granular textures found in the Southern Lagoon were not seen in the cores collected. The sequence is more poorly stratified than that in the Southern Lagoon, and there are no beds of laminated mud. Variations in the content of sand, shell and mud, and some colour variations, outline the bedding, mainly in units 2 cm or more in thickness, but the boundaries are commonly vague or transitional.

Northern Lagoon muds are composed predominantly of non-calcareous material. The calcium carbonate content of the silt plus clay sized fraction of six samples tested lay between 7 and 15%, (see Table 14). The non-calcareous fraction contains the same minerals as are found in the Southern Lagoon - quartz, a mica-type clay mineral, and a chlorite-type clay mineral. The calcareous component is entirely calcite, with no detectable aragonite.

(c) The Western Margin.

Along its western side, the central depression is bordered by a higher belt of sand, which in places has a broad and flat-lying surface a few inches below the low water level. At least two tongue shaped extensions of this

marginal deposit project nearly to the centre of the lagoon near the Seven Mile, but the detailed outlines of the deposit are not known.

The sands of this side of the lagoon are of two types. One is predominantly siliceous and similar to the platform sands of the eastern side, the other contains about 30% detrital calcareous grains, and is similar to the sands of the nearby Recent dunes.

Deformation of lagoonal muds has followed the advance of dunes into areas occupied by muddy sediments in two places near Pelican Point, where parallel anticlines and synclines have been formed at the base of the advancing dunes, (see page 176).

5. Organic Remains.

The lamellibranch Flavomala denacloides is found alive in the vicinity of Boundary Bluff and further to the north. It occurs buried slightly below the sand surface in some parts of the eastern platform which are permanently submerged. Shells of this species, Notopisula trigonella and Mytilus planulatus are the most common shells of the platform areas. Tests of Coxiella confusa, Diapheromactra versicolor, Ammonia beccarii, Elphidium spp. and other foraminifera are generally rare, but may be concentrated in some strandline accumulations. Diatoms, cogonia of Ohara and tests of the ostracod Species C are very rare or absent in the samples examined. Serpulid worms have formed

extensive biohermal deposits on the platform, and fragments of their tubes are common to abundant in some platform sands. The serpulid masses south of Boundary Bluff contained no living animals when examined, and were partly infilled by mud. Living serpulids are found to the north of Boundary Bluff. The worms have lived in the southern area recently, for some of the poles stuck into the lagoon floor by fishermen show an encrusting collar of the tubes close to the low water level.

In the central depression near the Seven Mile, N. trigonella inhabits the near surface muds, and paired and single valves are abundant in the topmost 12 inches or so of the sequence. Other shelly beds in the central part of the lagoon are composed predominantly of D. versicolor tests, but C. confusa, A. beccarii and F. donacoides are abundant. Elphidium and other foraminifera are common in the washed coarse fraction of samples at all depths. Ostracod tests of Species C are very rare to common throughout the sequence, but no tests belong to the Species A association of the Southern Lagoon were found. Diatoms are abundant throughout the muds of the central depression.

The macro-fauna of the region around Pelican Point is the same as that in the vicinity of the Seven Mile, but the micro-fauna is more varied, with a greater variety of foraminifera and a large number of sponge spicules. The Mottled Shore-crab Paragrapsus gaimardii (M. Edwards) is common throughout the Northern Lagoon, but is not found in

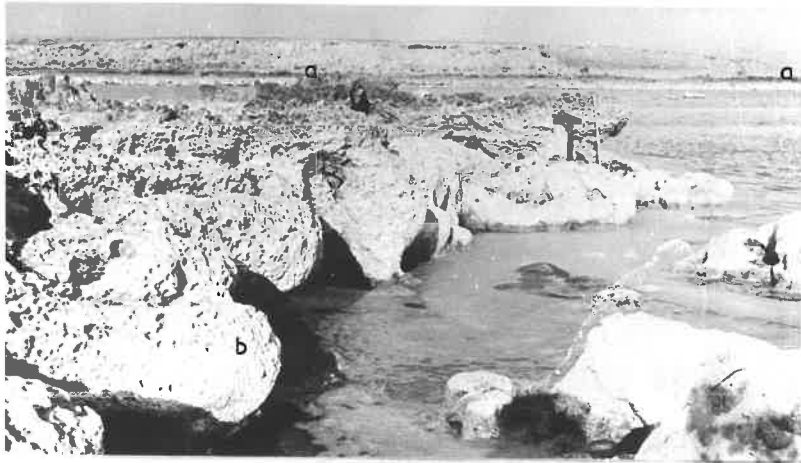
the Southern Lagoon. Fragments of the exo-skeleton of this crab are abundant in some strandline accumulations and are found along the shoreline of the Hell's Gate Passage.

The organic remains of the Northern Lagoon are mainly found in strandline deposits or in the sediments of the central depression. In the strandline deposits, shells of Fauna 1 organisms, most of which are now extinct in this area, are intermixed with remains of Fauna 2 organisms, as takes place in the Southern Lagoon. In the central depression of the Northern Lagoon, the shells, with the exception of those of N. trigonella, belong to Faunule B. Thus, the present environment of the Northern Lagoon is characterized by the presence of Faunule B and an abundance of diatom remains. This association is found in the sub-surface sediments of the central depression in the Southern Lagoon, suggesting that there was a period when the environmental conditions there were similar to those of the present Northern Lagoon.

PLATE 19.

Erosional features of the kunkar on the platform area,
1 mile north-west of Trevarrow's Point.

- A. Kunkar truncated slightly above the high water level to form an erosional surface (a). Note also the indurated bryozoan encrustations (b) around the outcrops from below the high water level. The scale is 24 in. long.
- B. Honeycomb weathering of the kunkar at the water's edge. The scale is 12 in. long.
- C. Algal encrustation (a) on kunkar (b). The scale is 6 in. long.



IV EROSION AND ENCRUSTATION OF ROCK OUTCROPS.1. Minor Erosional Features.

The framework of the marginal platform areas consists of kunkar outcrops which outline the shapes of eroded Pleistocene dunes. Throughout most of the Southern Lagoon, the kunkar and aeolianite have been eroded to form erosional platforms at two levels. One is at an elevation between the high water level and about two feet above that level. The uppermost surfaces of outcrops form a discontinuous sub-horizontal platform along parts of the eastern and western shorelines, and around some islands, (see Plate 19). The other is slightly above the low water level. It is shown in outcrops further out on the marginal platform and most of the mid-lagoon reefs have been eroded to this level.

Outcrops exposed to wave splash near the high water level have been extensively corroded, and various stages of honeycomb weathering have developed, (see Plate 19). The intensity of the corrosion is greatest close to the water on outcrops which face deep water. Further from the water edge, the corrosion becomes less intense, and only small, shallow pits are developed on the rock surface.

2. Encrustations.

Rock outcrops at the edges of the lagoon and on the mid-lagoon islands and reefs have formed the foundations for a variety of encrusting calcareous deposits, some of which

have formed extensive biohermal masses.

(a) Algal encrustations.

In the Southern Lagoon, kunkar which is submerged or wet for long periods is commonly covered by a very thin green film of microscopic algae. In several localities this algal film impregnates a thin layer of white micrite, less than 2 mm thick, which covers areas several square centimeters in extent. The encrustations are moderately hard, with an irregular surface, (see Plate 19). They are bound to the underlying rock, but can be flaked away by a sharp instrument. X-ray analysis of the encrusting material shows that it is composed of magnesium calcite and aragonite (see Table 17), whereas the underlying kunkar is composed of calcite alone. It is not known whether the algae cause the micrite to be deposited from the waters adjacent to the encrustation, or merely trap and bind lagoonal mud which settles on the algae.

(b) Bryozoan encrustations.

South of Policeman's Point, encrusting masses of bryozoans are found at or slightly above the high water level. They have formed around isolated rock stacks and have filled some erosional cavities. The colonies no longer contain living individuals, but the zoecia are friable and are not infilled with mud or secondary calcareous deposits.

Between the southern end of the Bul Bul Basin and Cattle Island, indurated calcareous encrustations are very

PLATE 20.

Indurated bryozoan encrustations.

A. Layered encrustations (a) surrounding kunkar (b).

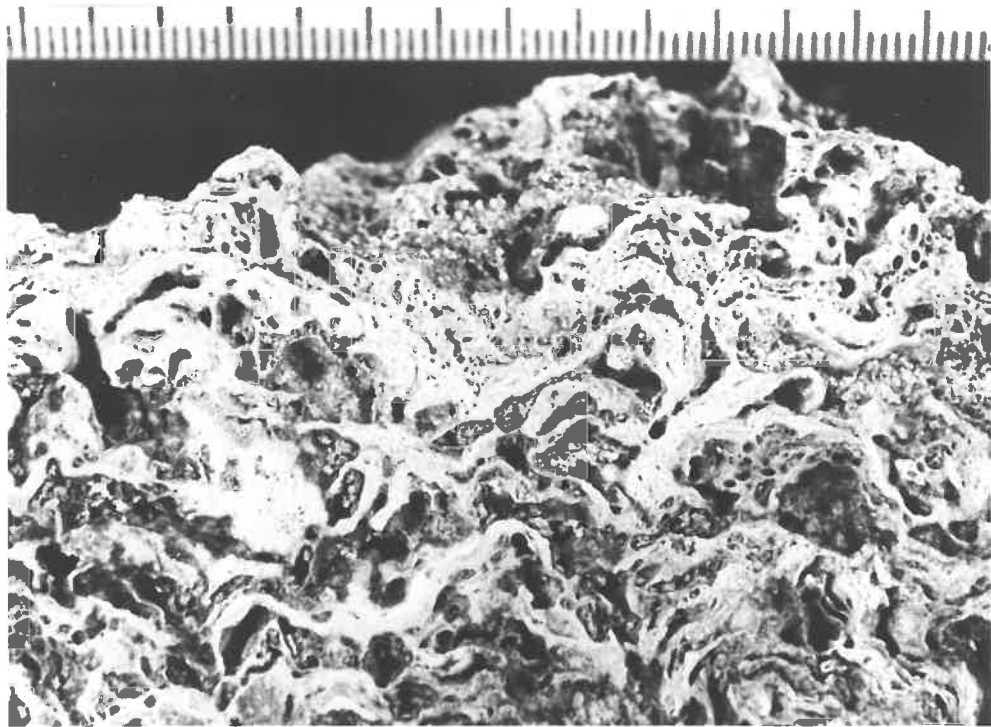
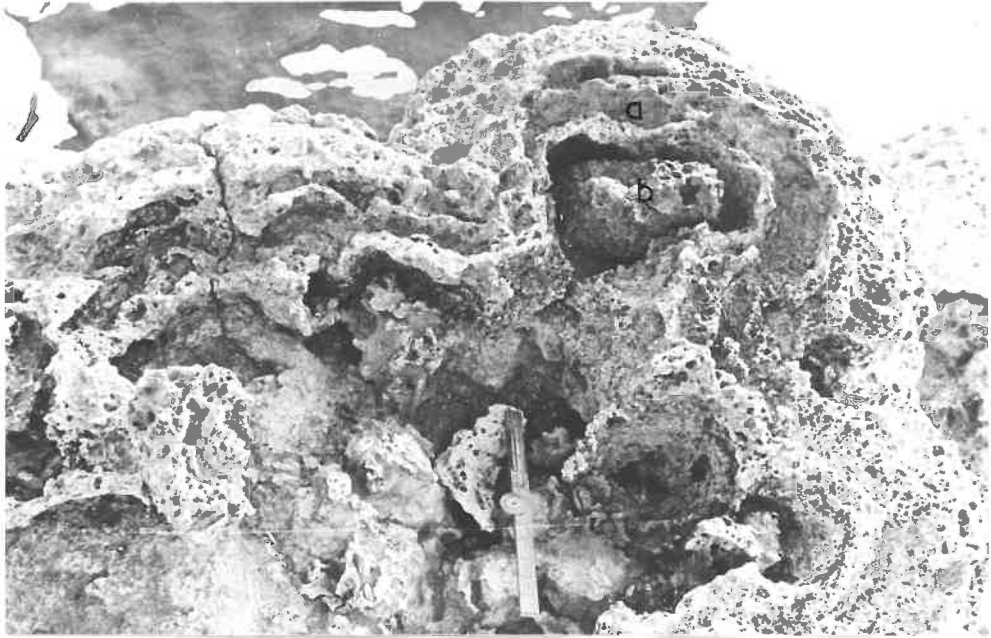
Scale is 12 in. long. 4 mile north-west of

Trevarrow's Point.

B. Cross-section of an encrustation showing the

porous nature of the encrusting mass and the

presence of zoecia. Scale is in cm. and mm.



common from slightly below the high water level to the low water level. They form bulbous projections around the margins of high outcrops, and completely envelop low rock masses to form dome-shaped biohermal accumulations, which may expand laterally and coalesce, (see Plates 19 and 20). The rock is crudely laminated and fills eroded cavities in the substrate in a manner similar to that of the friable bryozoan encrustations.

Thin sections of the rock show that it is composed of sheets of bryozoan zoecia which have been infilled by two types of secondary deposits and cut by secondary cavities.

The zoecia are often completely or partly filled by a deposit of sparry calcite. Secondary cavities and zoecia not completely filled by sparry calcite have been partly or wholly infilled by cloudy micrite. Within larger secondary cavities, the micritic fill includes many complete and fragmented shell remains, mainly Coxiella, Diaphoromactra, Ammonia and ostracod shells, and some quartz grains.

The secondary cavities are often several mm. in width and many cm. in length, cutting across the layers of the zoecia. Those which are not completely filled by secondary deposits are commonly lined by a layer of micritic material up to 0.5 mm thick. The walls of the secondary cavities, and some shell and quartz grains, have been covered by a single layer of zoecia in some places.

It is considered that these encrustations were initially formed as normal bryozoans encrustations similar to the

friable encrustations described previously. After the extinction of the bryozoan organisms, the deposits were subjected to modification. During this process, there were temporary returns to conditions favorable for the re-establishment of bryozoan activity.

Normally, bryozoans flourish only in waters of normal or near-normal marine composition, so it is likely that the colonies were formed at a time when the lagoon waters did not show seasonal compositional fluctuations as wide as those shown at present. It is unlikely that the organisms could tolerate periods of emergence as long as those which are imposed on the encrustations at present. Thus, it is likely that the original encrustations were formed at a time when the lagoon was more effectively connected to the ocean than at present. The restricted vertical distribution of the bryozoan encrustations suggests that their distribution was subjected to control by tidal oscillations of the lagoon's water level.

The presence of euryhaline shells in the secondary deposits within the encrustations suggests that the later modification of the colonies followed the development of more widely variable water compositions in the lagoon. This change in the nature of the lagoon water may have been one of the factors responsible for the extinction of the bryozoan organisms.

The secondary cavities have probably resulted from the development of an annual cycle of water level oscillations

involving long periods of emergence in the vicinity of the colonies. This would have exposed the encrustations to corrosion by wave splash and rain water. The lithification of the secondary deposits may also have resulted from long periods of emergence. During such times, interstitial water could evaporate and deposit calcium carbonate as a cement, binding muds and coarser detritus trapped within the colonies. The restriction of the secondary lithification to bryozoan encrustations which are largely within the present range of water level oscillations suggests that alternating long periods of inundation and emergence played a major role in the formation of this type of rock. Thus, the secondary lithification of the bryozoan encrustations probably followed a change from normal short-term tidal oscillations in water level to long term seasonal oscillations. This change may have been another factor contributing to the extinction of the bryozoan organisms.

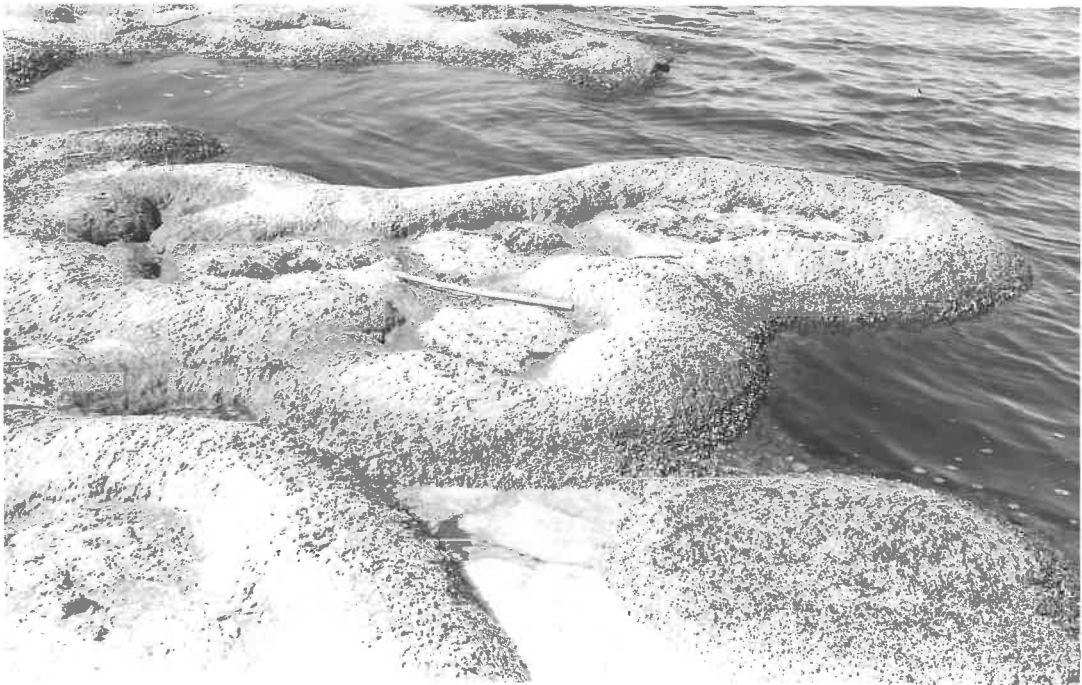
There are no permanent colonies of living bryozoans in the lagoon south of Boundary Bluff, but some may exist in the lagoon further to the north. During the spring of 1963, numerous small colonies were found established on rocks, pebbles and shells slightly below the high water level along the shores of the island chain south of Hack Point. These encrustations were up to 4 cm in diameter, and consisted of a single layer of zoeecia. It is thought that larvae had been washed southwards with the annual filling of the lagoon, and that the environmental conditions

PLATE 21.

Serpulid encrustations in the Southern Lagoon to the north of Cattle Island.

A. Rounded encrustations, partially and completely enveloping kunkar outcrops (k). Note the truncation of the kunkar close to the low water level, and the fibrous algal growth on the surfaces of the encrustations.

B. Serpulid-kunkar contact. Scale is $2\frac{1}{4}$ in. long.



had been temporarily suitable for their survival and growth.

(c) Serpulid encrustations.

In the Southern Lagoon north of Cattle Island, kunkar outcrops below the high water level are commonly encrusted by serpulid worm tubes, which form a deposit up to two feet thick. This cover can extend down to about five feet below the low water level, but it is not known whether the encrustation is very extensive at these depths, as the deep colonies could only be located by probing. On outcrops which do not project far above the low water level, the worms have completely enveloped the underlying rock, and have formed biohermal masses several feet across, (see Plate 21). Serpulid worms are no longer living in these encrustations. The tubes are largely filled with soft mud, and the open ends are covered by growths of long filamentous algae. The serpulid colonies in the Southern Lagoon are restricted to areas in which kunkar or aeolianite outcrops and the outcrops strictly control the distribution and the shapes of the colonies. Large rounded bodies develop around large outcrops of rock, but there is no tendency to form colonies like ^{the} large isolated bodies or small colonies such as are found in the Northern Lagoon.

In the Northern Lagoon, the distribution of serpulid colonies is less strictly controlled by rock outcrops. Large atoll-like and sinuous reefs on the eastern platform area suggest that kunkar outcrops controlled the initial stages in the development of the colonies, (see Plate 22).

PLATE 22.

Serpulid encrustations of the Northern Lagoon.

A. Linear bioherm extending towards the eroded kunkar
in the cliff-line at Seven Mile Point. The
hammer is 12 in. high.

B. An isolated bioherm near Dodd's Landing Point.
The anchor is about 15 in. across.



Later, the serpulids completely covered the kunkar foundation, and formed bioherms which spread laterally while still retaining the general outline of the foundation. The present bioherms are composed of closely spaced and coalescing hemispherical masses which are generally less than 2 feet in diameter. Towards the edge which faces out into the lagoon, the degree of coalescence increases and the outer edge of the bioherms may form a continuous band a few inches higher than the inner masses. Within the sheltered water on the lee side of the main masses, small isolated colonies a few inches in diameter lie scattered over the sandy platform floor. The small masses have formed around fragments of kunkar, shells, or fragments broken from larger colonies.

On the eastern platform of the Northern Lagoon, circular bioherms, several feet in diameter, extend up from the sand floor to the low water level, (see Plate 22). These colonies may occur far away from the nearest elongate reefs, and do not appear to be related to them. The nature of their foundation is not known, and there does not appear to be a regular pattern in their distribution.

The serpulid colonies in the Seven Mile region contained no living organisms when examined. The open ends of the tubes were partly clogged by mud, but there was no algal growth across the openings, and the tubes had a fresh appearance. The tubes are found encrusting fishermen's poles in the area, so the serpulids have evidently been alive recently. Between Boundary Bluff and Pelican Point, living

serpulids are abundant in the colonies. A few isolated worms were observed alive on rocks close to Stony Well Island in the Southern Lagoon during the spring of 1963. This was after a relatively large inflow of brackish water, and probably signified only a temporary return to conditions which the worms could tolerate. The general appearance of the colonies in the Southern Lagoon suggests that they were vacated many years ago, and it is considered that there has been no significant colonial growth for a considerable time. There has, however, been extensive growth of the worm colonies since the area was settled, for an old stone jetty on the shoreline of Youngusband Peninsula south of Stony Well Island has been firmly bound together by serpulids.

(d) Distribution of bryozoan and serpulid encrustations.

These two types of encrustation show different ranges of distribution along the length of the lagoon. South of Cattle Island, the lithified bryozoan colonies constitute all major encrustations and are everywhere found in direct contact with the underlying rock. Serpulid tubes are found singly or in small groups, but do not form thick encrustations. North of Cattle Island serpulid tubes form the outermost one or two feet of all encrustations and the tubes are commonly in direct contact with the rock foundation. Between Cattle Island and Stony Well Island there is an area of overlap, for in a few localities in that region, serpulid encrustations are separated from underlying rock by a layer of lithified bryozoan remains, from 6 to 12 inches thick.

These outcrops indicate that the formation of the bryozoan encrustations and part of their subsequent induration took place before the development of extensive serpulid encrustations.

The present distribution of serpulids appears to be controlled by the maximum salinity developed in summer months. The colonies do not at present thrive permanently south of Boundary Bluff. The worms can tolerate water compositions varying between brackish and hypersaline, but they do not survive in the areas in which the chlorosity rises in excess of about 30% in summer.

It is considered that the large bryozoan colonies were formed at times when the lagoon was more effectively connected to the ocean and the lagoon water was characterised by good circulation, with near-normal marine salinities for most of the year. There may have been periods of slightly brackish conditions, for the River Murray and Salt Creek probably exerted some influence on the environment at times when each flowed strongly. Later, the nature of the lagoon water changed, probably because of increasing limitations on its connection with the ocean. In the Southern Lagoon, water circulation became more restricted so that the lagoon began to show wide seasonal variations in water level and water composition. These changes were probably responsible, at least in part, for the extinction of the bryozoan organisms and for the subsequent lithification of the bryozoan encrustations.

The northern half of the Southern Lagoon was probably similar to the present Northern Lagoon at the time when serpulid colonies flourished north of Cattle Island. The lack of large serpulid colonies south of the island suggests that this area was characterised in summer by waters in which the chlorosity rose above 30‰. Some time after the building of the small stone jetty south of Stony Well Island, the colonies in the Southern Lagoon died out, and the tubes have been largely filled by mud and overgrown by algae. Still more recently, the colonies in the Seven Mile region died out. These changes in the distribution of serpulid colonies suggest that there have been increases in the maximum salinities attained during summer. These environmental changes probably reflect an increasing degree of restriction on longitudinal water circulation within the lagoon, which would lead to less efficient dilution of waters concentrated by summer evaporation.

PLATE 23.

An emerged embayment on the eastern shoreline of the lagoon immediately to the north of Seven Mile Point. This shows the cliff-line of the present shoreline extending inland and merging with a non-eroded dune surface.



Plate 23

V

EMERGED LAGOONAL SEDIMENTS.

In many places on both sides of the lagoon, there are indications that the lagoon was once more extensive than at present. Deposits of sand, shell and mud are found up to one half of a mile inland from the present shoreline. Most of the emerged deposits are located in depressions within the Pleistocene dune system, marking former embayments in the lagoon shoreline. Some of these embayments could possibly have been infilled by the lagoon while at its present water level, but there are a few localities in which the emerged deposits are located on elevated kunkar surfaces which are up to a height of about five feet above the present high water level, with the emerged deposits several hundred feet inland from the present shoreline. Such localities indicate that a relative lowering of water level has taken place since the development of lagoonal conditions. The nature of the sediment sequence indicates that the emerged deposits were all formed at the same time.

1. Margin outlines.

Most of the emerged sediments are found in a discontinuous series of small deposits, bordered by the lagoon shore on one side, and by kunkarized dunes on the landward side. The landward margins are continuations of the present shoreline cliffs, which show a progressive decrease in the degree of erosion inland, grading into non-eroded slopes at the far ends of the emerged areas, (see Plate 23). The

sapphire mud-flat to the west of the Ephemeral Lagoon is an emerged lagoonal area; this and a few smaller emerged areas along the western side of the lagoon are bounded by non-eroded slopes of the Recent dunes.

2. Topography.

The emerged areas form very gently sloping sand and mud-flats, lying only one foot or so above the high water line near the shore, and gently rising to about five feet above that level at the landward extremities. In a few areas, particularly in the vicinity of Salt Creek, a low dune of sand and shell has accumulated at the present shoreline. A vaguely defined series of parallel mounds are found slightly inland; these are probably low shoreline dunes, marking progressive stages in a regression of the shoreline. Along the landward margins of some emerged areas, a similar low dune ridge is found adjacent to the highest shell deposits, marking the maximum extent of the former inundation.

In some areas, notably in the vicinity of Trevarrow's Point and Haek Point, small ephemeral lakes, now completely isolated from the lagoon, are situated in low-lying parts of the emerged areas. In other low-lying areas, mud flats form swampy areas during the winter and summer months. Artificial swamps and lakes have been formed by the removal of shell grit for road-making purposes in some places.

Depth
(inches)
Surface

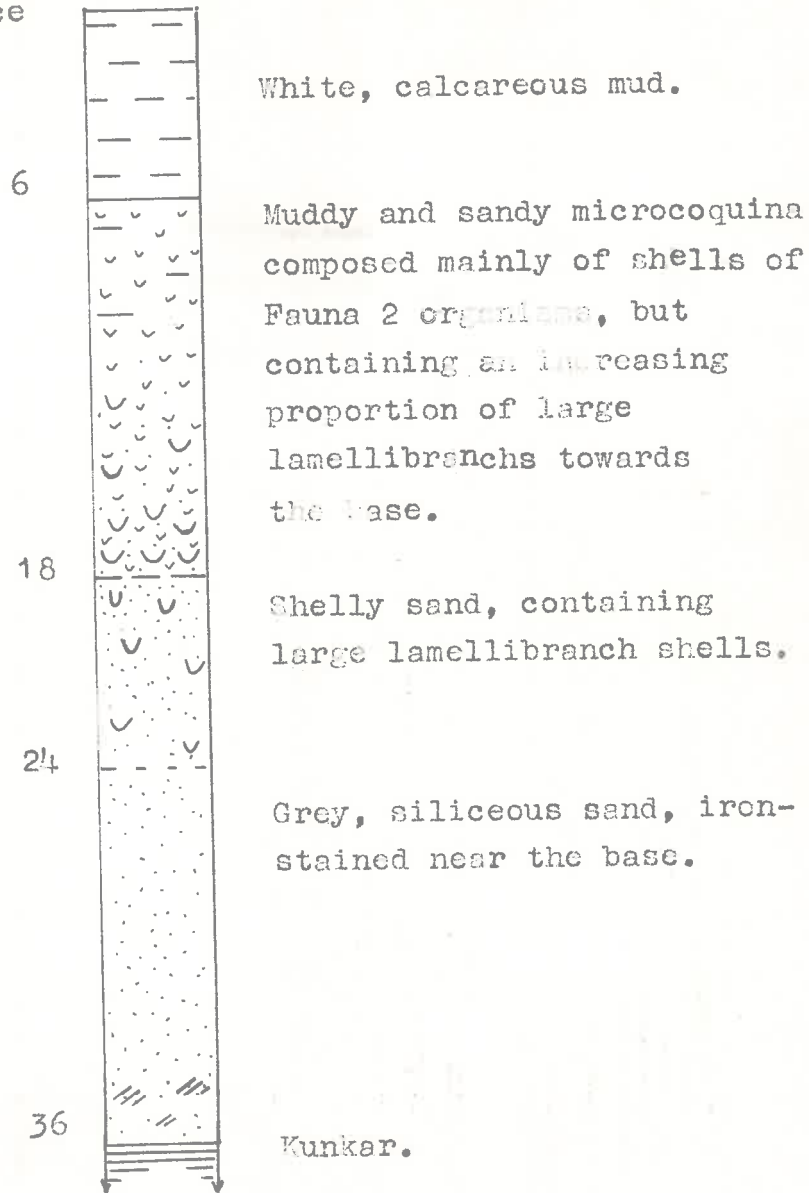


Figure 10.

Typical sequence of emerged lagoonal sediments.

3. Sediment Sequence.

The emerged sediments show a consistently developed sequence of sand, shell and mud beds. In at least one locality the sequence overlies the yellow siliceous sands which constitute the upper part of the weathering profile in the Pleistocene dunes, but in most localities, the base of the sequence lies on a hard layer of kunkar.

The basal unit of the sequence, as typically developed (see Fig. 10), consists of fine grained sands which show no obvious stratification. The lowermost part of the sand unit is practically free of calcium carbonate, but towards the top, scattered shells and fragments of the large lamellibranchs of Fauna 1 are found in increasing numbers. Near the base of the sands there is commonly a horizon which is mottled by the development of yellow-brown, ferruginous staining in patches a few mm. in diameter.

The basal sand grades upwards into a bedded shell unit, which contains varying and sometimes high proportions of interstitial sand and calcareous mud. Stratification is commonly well developed in this unit, and medium scale cross bedding has been seen in a few exposures, (see Plate 24). The shell material consists predominantly of tests of Coxiella confusa, Diaphoromastrea versicolor and Ammonia beccarii, but it also contains a high proportion of the remains of the large lamellibranchs of Fauna 1, particularly in the lower parts of the unit. Rounded and sub-rounded pebbles of kunkar are often present in this unit, and are

Emerged lagoonal sediments near Salt Creek Point.

These shelly sands are part of the shell unit in this sequence and are gently cross-bedded.



occasionally abundant.

In some localities, particularly along the landward margins of the emerged areas, the shell unit is the highest member of the sequence. Away from the margins, a bed of white calcareous clay, often shelly and sandy, forms a third unit, above the shell unit. The mud is commonly 9 inches or less in thickness, but in some of the isolated lake areas it is up to 24 inches thick.

The emerged deposits are covered in places by a dark grey sandy soil several inches thick, containing Coxiella, Diapheromactra and Ammonia tests. This deposit is probably a cover of wind-blown material derived from the present shoreline. In other places, the emerged deposits are partly covered by Sapphire plants, and a thin, slightly darkened limy soil may be present.

4. Nature of the component materials.

The basal sand unit is highly siliceous, and samples from the lowermost portion contain practically no calcareous grains. Higher in this unit, complete and fragmented shells appear with increasing frequency. The fragments are angular and show no signs of abrasion, but their surfaces are generally corroded. The quartz grains are very well sorted, with very few in the medium and coarse sand-sized fractions, (see Fig. 4). The larger grains and some of the smaller ones are sub-rounded to rounded, with a clear and glassy appearance, but most of the fine and very fine

sand-sized grains are of very irregular appearance, with angular and sub-angular edges and pitted surfaces. The sands of the shell unit and the mud unit are more calcareous, with a high proportion of angular to sub-rounded shell fragments, but the quartz grains are identical with those of the sand unit.

The shell material in the sequence consists of remains of both Fauna 1 and Fauna 2. The uppermost portion of the sand unit generally contains only members of Fauna 1. These are abundant in the lower parts of the shell unit, mainly as large fragments, but in some sequences they become less abundant towards the top of this unit. Remains of Disphoromactra, Coxiella and Ammonia generally form the greater part of the shell unit and of the shell fraction of the mud unit. Unidentified species of Elphidium and Miliolid foraminifera are rare to common. Tests of ostracod Species C and oogonia of Chara are rare to absent in the shell and mud units.

The silt- and clay-sized fractions of the mud unit and muddy portions of the shell unit are composed predominantly of calcite, with some silt-sized quartz, and, particularly in the northern localities, some argillaceous clay minerals, (see Table 15). In a few samples, traces of aragonite were detected, but this mineral was absent in most cases and, when present, it may be the result of contamination by shell material. In a few other samples, dolomite was detected, (see Table 15). The X-ray patterns of the dolomite are

similar to those obtained from the calcite-dolomite muds in the lakes south of the Ephemeral Lagoon by von der Borch (1962); he concluded that these dolomites were "proto-dolomite", this is probably the case with the dolomitic mineral in the emerged lagoonal sediments.

The X-ray patterns of the calcite in emerged sediments show that two forms of this mineral are present. The calcite of the shell unit produces a pattern with sharply defined lines and clearly developed high angle reflections. The pattern shows no significant variation of the d-spacings from those of normal calcite and the d-spacing of the (112) line indicates that the calcite is not magnesian, (see Table 15). Such calcite may well be of detrital origin. The calcite of the mud unit produces less sharply defined, broad lines, and the high angle reflections are not present. The pattern is consistently expanded, and the d-spacings of the (112) lines indicate varying proportions of magnesium in the calcite structure, (see Table 15). This type of calcite pattern is identical with that obtained from lagoonal and lake muds.

Rounded pebbles of kunkar are abundant in the shell unit in many localities at the landward edges of the emerged areas. In one locality, the content of these pebbles shows a progressive decrease away from the edge of the deposit towards the lagoon, but most sections are poorly exposed and do not present continuous cross-sections of the sequence.

5. Deposition

The absence of detrital calcareous grains in much of the sand unit, the shape of the quartz grains and the absence of lagoonal shells in the lower part suggest that these sands were deposited rapidly at an early stage in the transgression which led to the inundation of the emerged areas. The sands were probably derived from the siliceous sands which overlay the kunkarized Pleistocene dunes in the lagoonal area. At the earliest stages of the inundation, these sands would have constituted the most readily eroded source of detritus. The derivation of detrital calcareous grains would not have commenced until a later stage, when the less weathered parts of the Pleistocene dunes had been exposed.

During the deposition of the uppermost part of the sand unit, the members of Fauna 1 became established in the area, and commenced to contribute material to the sediments. These shells attain their maximum abundance in the overlying shell unit, where they occur mixed with shells of Fauna 2. As outlined previously, these two groups indicate markedly different water compositions in the lagoon area, and it is unlikely that the two groups were ever coexistent for more than a brief period of time. The concentration of shell material of Fauna 1 near the top of the sands and in the lower part of the overlying shell bed suggests that the rate of accumulation of detrital material decreased after the initial period of deposition. Following a change in the

nature of the aqueous environment from near normal marine to more widely variable conditions, Fauna 2 replaced Fauna 1 in the lagoon area. The nature of the sediments of the shell unit with well developed stratification and some cross-stratification, the presence of rounded kunker pebbles and a close similarity to the modern strandline deposits, suggests that this unit is a shoreline or near-shore accumulation. The admixture of the members of the two faunal groups has resulted from a low rate of supply of detrital material and the mixing of the surface and near-surface sediments in an area of relatively high turbulence.

The mode of formation of the mud unit is not entirely certain. Mud sediments have accumulated on the shallow platform areas of the lagoon, but these deposits are mainly in depressed parts of the platform which are not adjacent to the high water strandline. The shell unit below the mud unit indicates that the physical characteristics at the time of deposition of the emerged sediments were similar to those along the present near-shore area, so it is unlikely that the mud beds were deposited at the time of maximum inundation. The mud unit is therefore considered to have been deposited during or after the regression of the lagoon shoreline to its present position. Tests of the ostracod Species A are not found in the emerged muds. Although the tests of this species are fragile, it could be expected that some would survive in the relatively calm conditions which induced the muds to accumulate. Thus, their absence

suggests that the muds were deposited before the appearance of Faunule A in the lagoon.

Some of the emerged mud beds on each side of the lagoon are situated in localities which are partly separated from the lagoon by relatively high kunkar outcrops. In these localities, the regression may have isolated small lakes and swampy areas in which calcareous muds formed and were deposited above the shell beds. Alternatively, the muds may have accumulated by the process which is producing thin mud beds above the sands of the marginal parts of the Ephemeral Lagoon, and, to a lesser degree, at the shoreward ends of wide bays along the western side of the main lagoon. In these localities, wide and shallow areas of the lagoon floor dampen wave activity, and produce relatively calm conditions in which settling mud can form permanent accumulations, often with the stabilizing assistance of Samphire plants and periodic dessication. During or after the recession, parts of the emerged surfaces would have formed localities in which this process could take place.

Each of these two processes could have been responsible for parts of the emerged mud bed. The first process involves the formation of the mud within the area of deposition, in the manner in which the calcareous muds of the lakes south of the Ephemeral Lagoon were formed, von der Borsh (1962 and in press). There is some indication that this process has taken place, for the two samples in which the calcite shows an exceptionally high magnesium

content and all the samples containing dolomite are located in areas which are partly land-locked and which could well have contained isolated lakes. (See Table 15 and Fig. 17). The second process involves the deposition of muds largely derived from the main part of the lagoon. The mud beds not separated from the lagoon by topographically high areas, particularly the mud flats along the margins of the Sphemeral Lagoon, may have been formed by this process.

6. Summary.

The sediment sequence of the emerged areas shows a basal unit consisting mainly of detrital material deposited during the transgression which inundated these areas. The lowermost organic remains in the sequence indicate that sheltered marine conditions prevailed during the time of their formation. The underlying non-fossiliferous sands are probably the oldest lagoonal sediments encountered so far. Their deposition precedes the appearance, at least in the emerged areas, of shells of Fauna 1 which indicate an early phase of sedimentation within the lagoon. Later deposited sediments are composed mainly of shell remains and contain a record of an environmental change from sheltered marine conditions to more widely variable conditions, probably encompassing brackish, marine and, perhaps, hypersaline conditions. The top-most part of the emerged sequence indicates the presence of a lagoonal environment similar to that of the present time in which calcareous muds were being

deposited. The deposition of muds in the emerged areas along the margins of the lagoon suggests a relative lowering of the water level. This has finally left the deposits completely emerged, and in some cases far removed from the present reach of the lagoon waters.

(A) SANDS.1. Source.

The composition of the sands and the nature of their component grains show that the lagoon sands were derived from three sources. Sands derived from the Pleistocene dunes have been deposited along the margins of the lagoon and around dunes within the lagoon, and have probably been deposited, to a lesser extent, across the lagoon floor at the base of the mud sequence. Sands from the Recent dunes are being deposited along parts of the western shoreline, and have been more widely spread over the floor of the Ephemeral Lagoon. Lagoonal organisms have contributed sand-sized sediment to both the basin areas and the platform areas, but there has generally been little mechanical fragmentation and rounding of lagoonal shell material. Accumulations of small lagoonal tests have formed coarse and very coarse sand-sized microcoquina beds in the basin areas and the outer parts of the platform areas.

2. Deposition of Platform Sediments.

The sands of the platform areas have been mainly derived from the aeolianite and the overlying weathered material of the Pleistocene dunes. The sands were derived by wave erosion, which was largely confined to a narrow vertical interval close to the present water level. Lateral

spreading of the sands was confined to the vicinity of the eroded dunes, where they formed the gently sloping platform surface within a framework of resistant remnants of the truncated dunes. The outermost edges of the platforms form a steeply sloping face similar to the foreset of a delta constructed ⁱⁿ deep water, and probably little sand has been deposited in the deeper parts of the lagoon beyond the platform edges. The profile of the platform and its marginal slope suggests that wave-induced agitation of the lagoon floor played a major role in the transportation of sand-sized detritus and that wave and current movements in the lagoon waters were not sufficiently strong to spread much sand far from the eroded Pleistocene dunes.

At the time of the formation of the platforms, the lagoon area appears to have contained a relatively sheltered body of water which was subjected to slightly more agitation and movement than in the present lagoon. The fauna within the platform sands and the persistence of remnants of the relatively easily erodible dunes suggest that there was then a barrier between the lagoon area and the open ocean. In this case it is unlikely that there were much larger or stronger waves than at present. However, the fauna indicates that the lagoon was more effectively connected to the ocean than at present. This probably allowed tidal currents and tidal water level oscillations to affect the lagoon waters. Both would have assisted in the erosion of the Pleistocene dunes and the transportation of the sand-

sized detritus. The tidal oscillations would have led to frequent changes in the position of the wave base above which sands could be moved by wave agitation, so that much of the platform surface could have been subjected to frequent periods in which sands could be shifted.

In the present environment, ~~lagoon~~ wave-induced agitation of bottom sands is largely confined to the vicinity of the high and the low water levels. At the lower of these, the shallow slope of the platform surface dampens wave oscillations, so that there is generally little perceptible movement of sand. At the high water strandline, wave action stirs the bottom sands and ridges of sand and shell are accumulating in many places. The zone in which waves disturb the bottom sands is often very narrow; commonly perceptible agitation at any one time takes place within 1 or 2 feet of the strandline. Beyond this zone the sands are firmly compacted and rarely disturbed. Thus, over much of the platform surfaces movement of sands is now confined to relatively brief periods of time during the seasonal rise and fall of water level.

In most localities in the Southern Lagoon, the base of the shoreline cliffs is separated from the reach of the water by a protective barrier of beach deposits, low sand ridges and piles of rubblely kunkar and other debris. These barriers are often partly covered by low shrubs and grasses, and there appears to be little active erosion of the cliff-line by lagoonal waters at present. In the Northern

Lagoon north of Seven Mile Point, long sections of the cliff-line are still subjected to erosion and are actively contributing some detritus to the lagoon.

Thus, since the initial activity which produced the platform areas, there appears to have been little erosion of the shoreline cliffs or transportation of sand-sized detritus in the marginal parts of much of the lagoon. This change in the mechanical nature of the lagoon waters may have been a further result of the increasing degree of separation between the lagoon and the open ocean which is indicated by the faunal changes previously discussed. At the present time, sedimentation over much of the platform surface is confined to the accumulation of lagoonal shells, which are concentrated as a thin cover above the older sandy sediments in some parts.

3. Reworking of Recent dunes.

Recent dunes are encroaching on the lagoon area along parts of its western border. In some places the dunes have advanced well into the lagoon, and been subjected to constant attack by wave action. In these localities, the dune sands are being reworked and redistributed along the shoreline close to the dunes. Narrow sand shelves are being formed in a manner similar to that in which the older platform areas were formed around the Pleistocene dunes, except that in the case of the Recent dunes the source of the sands is constantly moving towards the water and the

PLATE 25.

Folded lagoonal muds along the western shore of the lagoon.

A. Folded muds at the base of an advancing dune at Bul Bul seep. Note the upward slope of the mud surface and the increasing intensity of the deformation towards the base of the dune.

B. A dissected anticline at F2, with mud-lumps in the background to the right of the fold. The hammer is 14 in. long.



PLATE 26.

Cross-section of an anticline at F2 showing tension cracks caused by folding and dehydration in mud beds and crenulation of fibre laminae near the crest of the fold. The scale is 12 in. long.

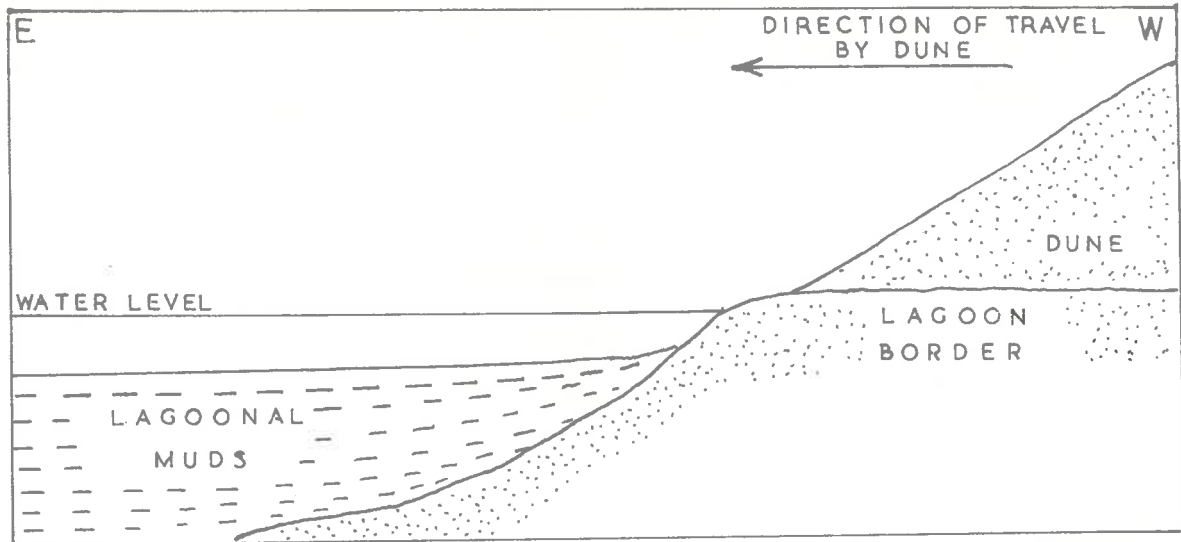


rate of sediment supply is probably much higher. The growing shelves are formed by wave action and long-shore drift caused by waves striking the shoreline obliquely. As the transportation is entirely by bottom traction, the deposits are localised and they have a steeply sloping slip face on edges facing deep water.

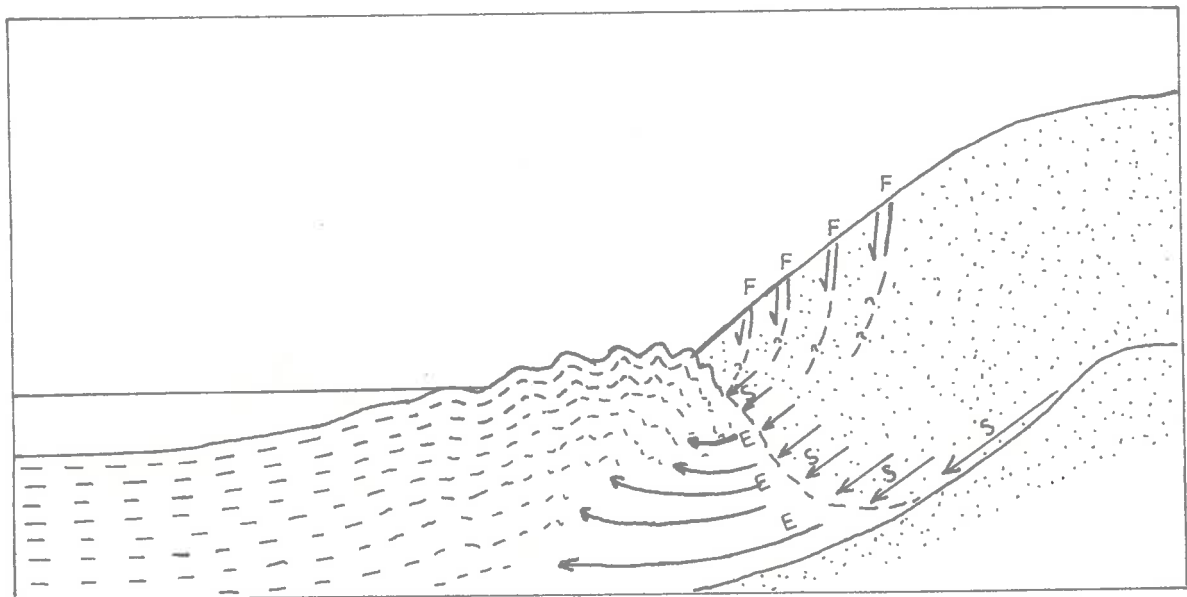
In a few localities, the dunes themselves or the sand shelves have advanced beyond the earlier deposited sands of the lagoon margins and are extending out on to the sequence of mud sediments. This has led to the rapid deposition of a heavy layer of sand above the plastic muds, thus causing the development of contemporaneous deformation structures in the muds and in the overlying sands.

In three localities within the Southern Lagoon, (F.1, F.2 and F.3 in Fig. 17) and at least two within the Northern Lagoon near Pelican Point, large dunes are moving onto lagoonal muds. In each case the encroaching mass of sand has squeezed the underlying muds from beneath the dune and the extruded mud has caused widespread uplifting of the lagoon floor near the dune, (see Plate 25 and Fig. 11). The uplifted muds have been folded into a regular arrangement of long anticlines and synclines in which the fold axes are arranged parallel to the outline of the drift which initiated the deformation. Erosion has truncated the anticlines in a few cases, revealing cross-sections of the folded mud sequence, (see Plates 25 and 26). Cracks up to several inches wide have developed across and along

The probable mode of formation of deformation structures near the contact between sand dunes and the lagoonal muds.



(i). The situation before a dune reaches the lagoon.



(ii). The situation after the dune encroaches on the muds.

- F faults in the dune sands.
- S direction of slip by the dune sands.
- E direction of flow by the extruded mud.

the folds, probably as a result of tension caused by the folding process and by the drying of the muds after uplift. These cracks have aided the erosion of the uplifted anticlinal folds, so that waves are able to remove whole blocks of mud. The edges of the blocks become rounded and they are easily moved by the water to be deposited as mud pebbles within the sands near the folds, (see Plate 25).

Most of the anticlines are slightly asymmetrical, with the axial surfaces generally dipping towards the base of the approaching dune. The deformation is most intense close to the dunes, where the bedding of the muds may be overturned on the fold-limb which is further from the dune. There is a tendency for anticlines close to the dune to show bulbous upwellings or to rupture. Away from the dune, the intensity of deformation decreases, and the folding becomes progressively more open and more widely spaced.

The regular arrangement of the fold axes suggests that there are compressional forces acting in the plane of the uplifted sediment surface in addition to the upward-directed forces exerted by the displaced mud. It is considered that the encroaching dune mass slips lagoon-wards as it sinks into the mud, (see Fig. 11), and compresses the uplifted surface into a series of folds parallel to the dune outline.

As the dune founders, it behaves as a moderately coherent body, possibly as a result of the cohesion produced in damp sub-surface sand by interstitial water, and it breaks into a number of fault blocks. After a period of

PLATE 27.

Fault traces across a dune surface at Bul Bul seep.

A. A long crack in the sand surface. The scale is
24 in. long.

B. Cavities left by sand draining down along a
fault plane.



An east-west cross-section of a fault at Bul Bul seep. Note the downward increase in the displacement of the lettered beds and the presence of minor faults (m). The apparent change in the dip of the bedding near the scale is caused by a change in the orientation of the pit-face. The scale is 12 in. long.



one or two windless days, the surface of the dune near the folded muds is traversed by a series of cracks, (see Plate 27). Cross-sections of the cracks show that they delineate narrow fault planes which have been traced to a depth of three feet, and probably extend further. These are normal faults, with the fault planes dipping towards the lagoon at angles close to 80° . The displacement of bedding planes in the sands across the faults increases downwards, (see Plate 28), indicating that there has been continuous or periodic movement along individual planes over a considerable period of time. Associated with the major faults are a number of smaller faults which have been active for only short periods, after which they have been covered by undisturbed sands. The attitude of the fault planes indicates that the base of the dune-front is bodily moving lagoon-wards as the dune settles into the mud.

Similar deformation structures are forming on a reduced scale along the outer edges of sand shelves above the lagoon muds. In these cases the deformation is confined to two or three anticlines which occur at or beyond the outer edge of the shelf. These folds are not as regular as those associated with the dunes and often they consist only of ridges of irregularly contorted mud.

(B) MUDS.1. Deposition.

Although the intensity of agitation produced by wave action and water circulation within the lagoon is insufficient for moving sands over much of the platform surface, it is sufficient to control the permanent accumulation of fine grained and lighter material. Muds and light organic detritus are accumulating in areas of deep water, small depressions on the platforms, sheltered embayments and at the landward margins of wide and very shallow stretches of water, where agitation of the bottom sediments is greatly reduced. In the Bul Bul, Cattle Island and Stony Well Basins, the mud sequence has accumulated up to the level of parts of the platform surface, and there is no longer a marked topographic differentiation into areas of turbulence and relative quiescence. In these basins muds are now being more evenly distributed across the lagoon floor, whereas in the deeper basins to the south, there is a strong tendency for muds to be preferentially deposited in the less disturbed basin floors.

The low degree of agitation on the basin floors is reflected in the relatively thin stratification, particularly in the southernmost basins, where laminated sediments form a significant portion of the sequence. The absence of stratification within some beds is probably due to contemporaneous and post-depositional changes produced by

organic activity. Pellets similar to those found in the sediments were seen within small worms which live in the near-surface muds and burrows filled with pellets were encountered in a few cores. The beds of pelletal mud indicate that at certain times organic activity has altered much of the surface and near-surface muds. The sharp basal contacts and the absence of fine interstitial mud in some pellet beds suggest that in some cases pellets have been concentrated by transportation or the winnowing action of gentle water currents.

Many of the beds of granular mud contain scattered whole and incomplete pellets or show faint outlines of merging pellets. This suggests that the mud aggregates have been formed by the partial disintegration of pellets, either at the surface or within the mud sequence. As the pellets are not indurated, they are probably deformed and partly disaggregated by the slight pressures associated with compaction or when the binding mucus decomposes.

2. Origin.

(a) Argillaceous component.

At times of strong river flow, mud laden waters of the River Murray move southwards along the Southern Lagoon. In the absence of other streams entering the lagoon, it is assumed that the argillaceous component of the lagoonal muds have been derived from this source. The ready access of river waters to the Northern Lagoon is reflected in the high

proportion of argillaceous clays in the muds there. The restricted access of river waters to the Southern Lagoon is reflected by a much lower proportion of argillaceous clays in the muds south of Hack Point. The southward decrease in the proportion of argillaceous clays in surface muds of the Southern Lagoon is probably due mainly to the limited degree of longitudinal water circulation, although it may be partly due to a higher rate of formation of calcareous mud to the south. This last factor is probably of more importance in the area south of Salt Creek Point, where the seasonal changes of water conditions are more accentuated than in the remainder of the Southern Lagoon.

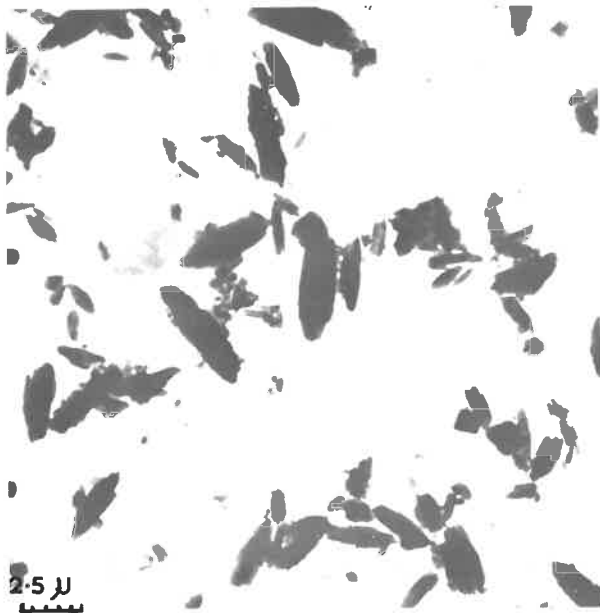
(b) Calcareous component.

(1) Source.

The loss of dissolved calcium from the lagoon waters as the salinity rises (see page 64) suggests that part or all of the calcareous component of the muds has been derived by precipitation from the lagoon waters. There is no transportation of aragonite or magnesian calcite into the lagoon by streams from external sources. Abrasion of lagoonal shell material is taking place on only a limited scale along the shorelines. The pink sands and other chalky parts of the weathered Pleistocene dunes may have acted as a ready source of calcite while the dunes were being eroded, but the dunes are no longer subjected to erosion by lagoon waters along most of the Southern Lagoon.

In X-ray diffraction photographs, the magnesian calcites

Electron photomicrographs of muds from the
Ephemeral Lagoon.



show expanded patterns, with broad lines and an absence of high angle reflections. None of the examined samples from the central depression showed indications of the presence of sharply defined normal calcite patterns, such as are obtained from the chalky calcite of the dunes. Thus, there is no sign of unaltered detrital calcite in the muds of the central depression. It is not known for certain whether or not fine grained detrital calcite has been deposited in the lagoon during the accumulation of the known part of the mud sequence, and there altered to magnesian calcite. However, as it is unlikely that fine grained calcite has been eroded from the Pleistocene dunes along the shores of the Southern Lagoon for some time, it is considered that the magnesian calcite deposited there has probably been derived by precipitation from the lagoon waters. The source of the calcite in the Northern Lagoon is not known.

In laboratory experiments, aragonite and magnesian calcite are co-precipitated from concentrated sea waters in which the temperatures, pH and compositions of dissolved salts are similar to those of lagoon waters, (Alderman, in press). Artificially precipitated aragonite generally develops as needle-shaped crystals, whereas the lagoonal muds are made up of lathe-shaped grains, up to 6 microns in length, (see Plate 29). The grains are most commonly 1 to 4 microns long, with their length two to four times their breadth. There is no clear differentiation of grain shapes to suggest specific identification of aragonite and calcite

grains. However, the grains do appear to be discreet crystals and some are similar to aragonite crystals figured by Cloud (1962).

The absence of an external source of aragonite and the shapes of grains in the lagoonal muds suggest that the aragonite of the Southern Lagoon has been precipitated from the lagoon waters, along with the magnesian calcite. Experimental work carried out in this Department, (partly summarised by Alderman, in press), indicates that such a co-precipitation is likely in the waters of the Southern Lagoon.

(11) Environmental controls.

Apart from within the vicinity of the Hell's Gate Passage, the surface muds along the length of the Southern Lagoon contain above 50% calcium carbonate, with the carbonate content everywhere composed of aragonite and magnesian calcite. The muds of the Northern Lagoon contain less than 15% calcium carbonate, entirely in the form of calcite. The environmental factors which are most likely to have been responsible for the precipitation of calcium carbonate and the deposition of muds having a high carbonate content in the Southern Lagoon are:

- 1) The rate of supply of argillaceous material is low.
- 2) The large annual increase in salinity due to evaporation is entirely within the hypersaline range, and therefore leads to the development of very high salinities. The chlorosity ranges

from 20-30% in winter to above 50% in summer.

3) As the salinity increases, the average temperature of the main water body increases from about 12°C to 20-25°C.

4) The pH is maintained at moderately high values, between 8.25 and 8.50, in the main water body.

All four of these factors have probably assisted the precipitation of calcium carbonate and the deposition of highly calcareous muds. However, the main factors are probably 1) and 2), for it is in these two aspects that the Northern and Southern Lagoon differ most markedly.

The absence of aragonite in the muds of the Northern Lagoon suggests that the higher range of the annual salinity change in the Southern Lagoon is the main factor controlling the precipitation of aragonite from the lagoon waters. Water temperatures of the Northern Lagoon are similar to those of the Southern Lagoon, particularly in the tide-less Seven Mile region. Although pH values may be slightly lower in the Northern Lagoon than in the main part of the Southern Lagoon, the lowering of pH in the waters of the Bul Bul Basin is not associated with any observable deficiency of aragonite in the surface muds. The higher rate of deposition of argillaceous material in the vicinity of the Hell's Gate Passage has caused greater dilution of the carbonate component there than further to the south, but it has not altered the mineralogy of the carbonates deposited.

Aragonite-rich muds form only a thin surface cover in

the Stony Well Basin, suggesting that the precipitation of aragonite has been proceeding in that locality for a relatively short period of time. In the basins south of Cattle Island, the aragonite-rich muds are thicker and have probably been forming over a longer period of time. The recent extinction of serpulid colonies in the Stony Well Basin indicates that chlorosities in excess of about 30‰ have been developing in that basin only within historical times. The absence of major serpulid encrustations in the Southern Lagoon south of Cattle Island indicates that chlorosities higher than 30‰ have been developing, at least from time to time, in that part of the lagoon for a considerably longer period of time. Thus, these relationships between the thickness of aragonite-rich muds and the presence of serpulid encrustations support the suggestion that the precipitation of aragonite is dependent on the salinity range shown during the annual cyclic change of water composition.

The vertical distribution of aragonite in the mud sequence of the Southern Lagoon was probably controlled by the nature of the depositional environment. The sudden decrease in aragonite content shown in all the cores examined may have been caused by inversion of aragonite to calcite, but this is considered to be unlikely. Aragonite is reported to be relatively stable when in contact with sea water or with interstitial waters similar to those with which it was precipitated, (Ingerson (1962) and Cloud (1962)). The chlorosity of interstitial waters in core G.40 remains

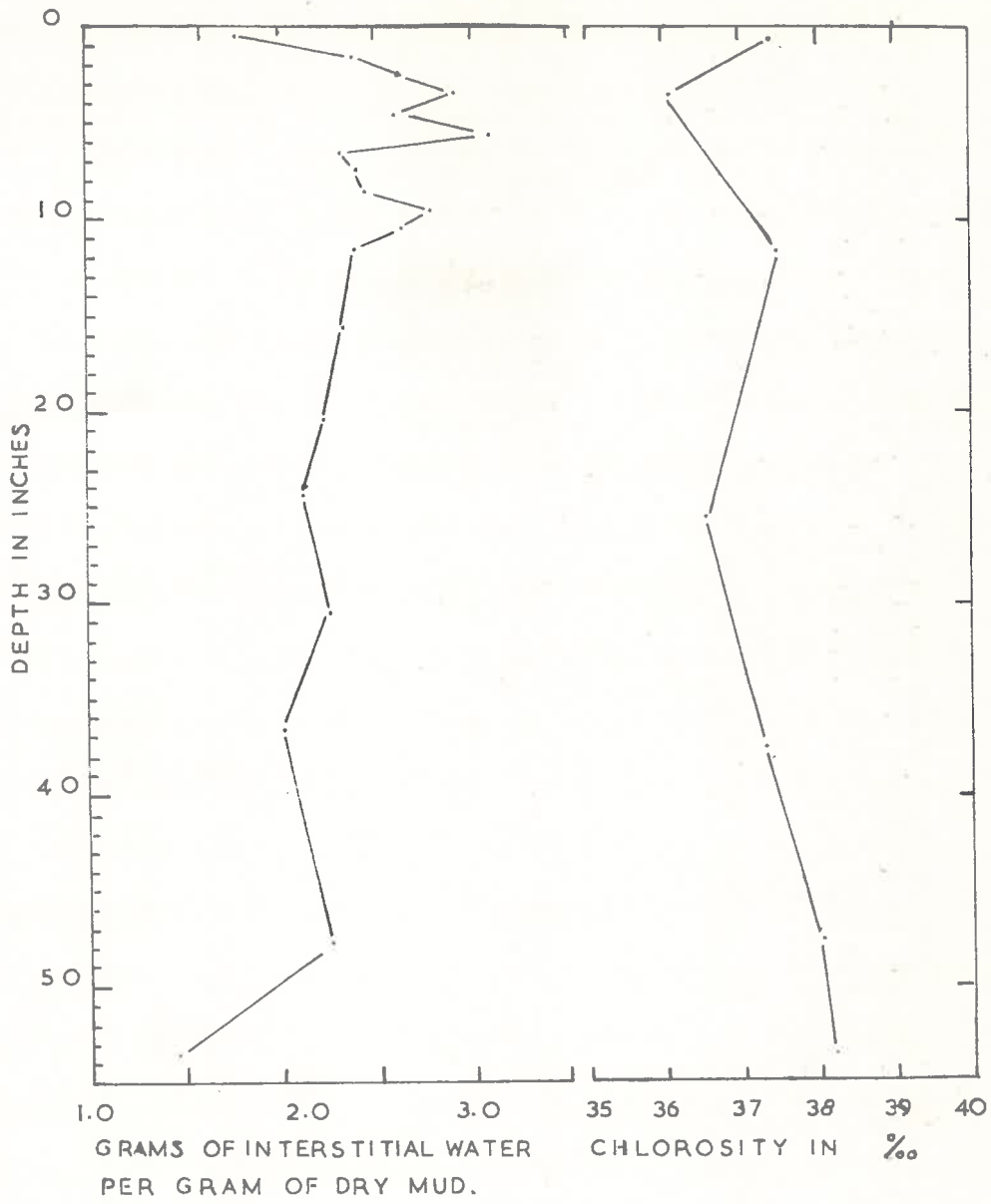


FIGURE 12
 INTERSTITIAL WATER IN CORE C.40.

between 35% and 40% down to a depth of about 5 feet (see Fig. 12). This indicates that there has been little or no replacement of interstitial water in the muds. Thus, it is likely that aragonite could be stable within the mud sequence in the central depression. Aragonitic shells show no sign of inversion in the sequence. Although this does not prove that there has been no inversion in the fine-grained mud, evidence of inversion in the shell material would have indicated the likelihood of inversion in fine-grained aragonite.

The possibility that the vertical change in aragonite content is a depositional feature is suggested by the northward decrease in the depth at which this change is found and its closeness to a marked change in total carbonate content in the muds between Salt Creek Point and Hack Point. The close association between these two changes suggests that the precipitation of aragonite with magnesian calcite rather than magnesian calcite alone is a result of a higher rate of carbonate precipitation. Thus, it is most likely that the control of aragonite precipitation exerted by the range of the annual salinity change is indirectly achieved by the influence of the salinity on the rate of carbonate precipitation.

The sub-surface changes in the magnesium content of calcite in the muds of the basin areas ^{are} ~~is~~ not related to the above mineralogical changes. It is not known whether this change is a primary feature reflecting a change in the nature of the calcite precipitated or a post-depositional change which has taken place within the mud sequence.

(C) SUMMARY.

Most of the sands deposited within the lagoon have been derived from the Pleistocene dunes. The erosion of the Pleistocene dunes and the deposition of platform sands appear to have been effected mainly during an early period in the history of the lagoon. After the production of the platform areas around topographically high areas of the pre-inundation land surface, transportation of sands and erosion of the lagoon shorelines were greatly reduced. At present the movement of sands is largely confined to the vicinity of the high water strandline. Along the western side of the lagoon, some Recent dunes are being eroded and the sands re-deposited in the form of sand shelves close to encroaching dunes. These deposits and the dunes themselves have caused striking deformational structures to develop where sands have been deposited above the lagoonal muds.

The muds of the lagoon are principally deposited in the deep waters of the central depression. The composition of the muds reflects the partial separation of the lagoon into its northern and southern parts. Muds of the Northern Lagoon, which is closer to the River Murray and the ocean connection, have a high proportion of argillaceous material and a low carbonate content. Those of the Southern Lagoon have a moderate to high carbonate content, reflecting the isolation of this part of the lagoon from the River Murray and the ocean. This isolation has resulted in a low rate of supply of argillaceous material and the creation of an

environment suitable for the precipitation of calcium carbonate from the lagoon waters. Aragonite and magnesian calcite are being precipitated as a result of evaporation of water in which the dissolved salts are principally derived from the ocean. Precipitation has been assisted by the development of moderately high temperatures and pH values, and by the seasonal development of very high salinities.

THE EVOLUTION OF THE LAGOONAL ENVIRONMENT.

EVOLUTION OF THE LAGOONAL ENVIRONMENT.

As the sea level rose during the early part of the Recent, the ocean shoreline of the South East of South Australia moved eastwards towards its present position. The maximum eastward extent of the transgression was probably controlled by the line of the Pleistocene dunes which now outcrop along the eastern side of Younghusband Peninsula. Portions of the western sides of these outcrops have been eroded by lagoon waters to form low cliffs, but there is no indication that the exposed portions were subjected to attack by the open ocean waters. It is likely that sand dunes accumulated in front of the advancing shoreline, particularly towards the end of the transgression, when the rate of rise in sea-level was much slower (Shepard 1964). Within the last 6000 years or so, the rate of rise of sea level has been relatively low (Shepard 1964) and it is likely that for much of this time, the shoreline has remained close to the present position, where the eastward transgression was stopped or slowed by the presence of the Pleistocene dunes. As the sea rose to its present level, sand dunes accumulated to higher elevations, and the rising water level led to the inundation of the area behind the dunes, thus creating the lagoon.

Unfortunately, the maximum depth of the base of the lagoonal muds is not known. The deepest part penetrated showed muds to a depth of 11 feet below the sediment surface,

at a point south-west of Trevarrow's Point, where the lagoon floor is about 14 feet below the high water level. This shows that the muds extend to a depth of at least 25 feet below the present sea level. Assuming that the deepest muds are lagoonal deposits, and that there has not been excessive regional upwarping, this depth indicates that the lowest known part of the mud sequence can be no older than about 6000 years B.P., (from Fig. 2 in Shepard (1964)). As the mud was probably deposited below the water level of the time, rather than at that level, it is likely that the lowest known mud is of an even younger age. Probably the lagoon is not much older than about 6000 years B.P., for prior to this date, the eustatic rise in sea level was relatively rapid and it is unlikely that the base of the lagoonal sediments is far below the deepest known section.

The organic remains and the sediments of the lagoon indicate that there were two distinct phases of sedimentation during the history of the lagoon.

1. The Sheltered Marine Phase.

The earliest known lagoonal sediments are the sands of the emerged areas and the platform areas. The lowermost organic remains contained in these sediments belong to Fauna 1, showing that at the time of their deposition, the lagoon waters were of near normal marine composition. The lagoon was probably more effectively connected to the ocean than at present. The emerged sediments show that the

water level in the lagoon was at a higher level relative to the land surface than at present and that the lagoon was more extensive during this period. It spread into the low-lying areas east of the Ephemeral Lagoon and south-eastwards along the whole length of the Coorong towards Kingston. Sprigg (1952a) considers that there was an opening at the southern end of the Coorong during the period when the lagoon extended to Kingston.

Erosion of the Pleistocene dunes during this period produced the platform areas of the lagoon and formed the shoreline cliffs, including those at present stranded above the water line on the western sides of the Pleistocene dunes on Youngusband Peninsula and those in the emerged embayments.

The flow of fresh water from the River Murray and Salt Creek probably caused slight dilution of the lagoon waters during winter and spring months. Better connection between the lagoon and the sea would have resulted in less dilution than is found in the present Northern Lagoon. It is also likely that the salinity rose during summer due to evaporation, but the circulation of sea water would have prevented the development of strongly hypersaline conditions.

There is no direct evidence, such as deposits of ocean shell material, in the lagoon or on Youngusband Peninsula to indicate where connections may have existed between the lagoon and the ocean, other than at each end of the Coorong. Other connections may have existed, and evidence of their presence since been covered by lagoonal and dune deposits.

Sands similar to the Recent dune sands are abundant across the floor of the Ephemeral Lagoon, and it is possible that these sands were derived from areas where the ocean waters were able to cross over breaks in the dune barrier.

There is a sudden change in the nature of the sand surface of the Coorong floor at the northern end of the Ephemeral Lagoon. In the Ephemeral Lagoon and the Coorong to the south, the sand surface is relatively flat, and situated close to the present sea level. But to the north of the Ephemeral Lagoon, it suddenly plunges below the muds of the basin areas, descending to a depth of at least 25 feet below sea level, while its profile becomes very irregular. Further, the sands in the Ephemeral Lagoon contain a high proportion of material derived from the Recent deposits, whereas those adjacent to, and underlying the basin areas have been derived mostly from the Pleistocene dunes. These changes in the character of the sands may reflect differences in the Pleistocene topography on which the sands were deposited, but the absence of kunkar outcrops west of the eastern margin in the Ephemeral Lagoon and in the Coorong further to the south does not suggest this. It is considered to be more likely that sands derived from the Recent ocean coastline were abundantly supplied to the part of the Coorong south of Bul Bul Basin and rapidly filled this part of the Coorong. They may have been swept across low-lying parts within the dune barrier by ocean waters at times of storms or high tides, and then reworked by the lagoonal

waters.

2. The Restricted Lagoon Phase.

The sheltered marine environment was replaced by one in which the euryhaline organisms of Fauna 2 flourished. In the new environment, wider variations in water composition were shown, probably as a result of seasonal fluctuations in the rates of inflow of fresh water and intra-lagoonal evaporation. It is likely that the wider seasonal fluctuations of water composition were caused by a reduction in the degree of connection between the lagoon and the ocean. This reduction was probably brought about by the closing of breaks in the dune barrier and the constriction of the extremal connections. The connection at the southern end of the Coorong probably closed completely at this time.

When the lagoon became more isolated from the ocean, fresh waters from the River Murray and Salt Creek would have caused more marked dilution at times when each flowed than during the sheltered marine phase. At the same time, evaporation during summer would have produced higher salinities, as the lagoon was largely cut off from the moderating influence of the sea water circulation. The nature of water level oscillations would have been affected, with short-term tidal oscillations being replaced by seasonal oscillations. These extremes led to the extinction of many of the faunal elements formerly present. Of the larger lamellibranchs, only two, Notospisula and Flavomala,

have managed to survive. Both are confined to the Northern Lagoon and neither are very abundant.

Some time after the development of the restricted conditions, a relative lowering of the lagoon water level led to the stranding of the emerged lagoonal deposits. Although the restricted conditions are reflected in these deposits, it is possible that the shell beds containing an abundance of Fauna 2 remains were deposited at a time when the lagoon water level was slightly lower than during the sheltered marine phase. It is likely that the restricted lagoonal phase was produced by a lowering of water level and that the appearance of Fauna 2 in the emerged deposits marks the beginning of the regression.

The evidence of a certain lowering of the water level within the lagoon suggests that the emerged ocean beach deposits along the western side of Younghusband Peninsula were left stranded by a contemporaneous lowering of the sea level relative to the land surface. It is likely that such a marine regression was a major factor in the initiation of the restricted lagoonal phase. A marine regression could have been responsible for the closing of tenuous connections between the ocean and the lagoon across Younghusband Peninsula and at the southern end of the Coorong, leaving the deep river mouth as the sole connection.

The reduction in the intensity of erosion of the shore-line cliffs and in the amount of sand transportation across the platform areas was probably a result of the restriction

imposed on connection between the lagoon and the ocean. This effect may have followed the destruction of tidal influence within the lagoon. Since that time, sedimentation on the platform areas has been confined largely to the accumulation of microcoquina deposits in parts of the platform and the building of beach deposits along the high water strandline.

The known part of the mud sequence in the central depression is characterized by the presence of Fauna 2 and therefore must have accumulated during the restricted lagoonal phase of sedimentation. However, it is not known how long after the commencement of this phase the deepest collected muds were deposited.

Within the central depression of the Southern Lagoon, the interval of change in aragonite and total carbonate contents and the interval of transition from Faunule A to Faunule B both appear to be responses to increases of the maximum salinity or the range of salinity shown during the annual cycle of water compositions. Although they do not show a persistent vertical relationship, they either coincide or are closely situated in the sediment sequence. It is therefore considered that the sediment sequence in the central depression of the Southern Lagoon can be broadly divided into two parts, marking minor sub-divisions of the phase of restricted lagoonal sedimentation. This sub-division is similar to the present differentiation of the Northern and Southern Lagoon.

(a) The Estuarine Sub-phase.

The lowermost part of the sequence is characterized by the presence of Faunule B, magnesian calcite as the major carbonate mineral and a relatively low carbonate content in the muds. The presence of Faunule B and, to a lesser extent, the carbonate content of the muds, suggest that these sediments were deposited in a moderately extreme environment, similar to that of the present Northern Lagoon. The range of the annual salinity changes was probably lower than that of the present Southern Lagoon and both this and the higher proportion of argillaceous muds suggest that the Southern Lagoon was subjected to a higher rate of inflow of fresh water. Thus, at this time the Southern Lagoon showed estuarine characteristics similar to those found in the present Northern Lagoon.

The annual cycle of water composition probably extended from brackish to marine or hypersaline conditions. Hypersaline conditions certainly developed during part of the annual cycle in the area south of Gattle Island, as indicated by the moderately high carbonate content of the muds there and the absence of any major serpulid encrustations. The flow of fresh water from Salt Creek Point may well have had a moderating influence on the Southern Lagoon during this time, and may have been partly responsible for the estuarine characteristics.

(b) The Highly Hypersaline Sub-phase.

The uppermost part of the restricted lagoon phase in

the Southern Lagoon is characterized by the presence of Faunule A, aragonite as the major carbonate mineral and a moderate to high carbonate content in the muds. These characteristics appear to be related to a depositional environment similar to that of the present Southern Lagoon and thus indicate a high range of salinities during the annual cycle of environmental conditions. The present environment is characterized by a salinity cycle entirely within the hypersaline range, but it is unlikely that this is a necessary pre-requisite for the development of the type of sedimentation which proceeded during this sub-phase.

It is likely that fresh water flow from Salt Creek would have caused at least some lowering of salinities throughout the Southern Lagoon in the winters of most years until about the year 1920 A.D. when regular fresh water flow ceased.

The construction of an artificial drainage system southeast of Kingston about the year 1920 halted the flow of water through Salt Creek in all but very wet years. Further construction of drains since 1950 has led to what is probably a permanent halting of water flow through the creek. Since the cessation of influx from Salt Creek, the waters of the Southern Lagoon can be diluted only by waters of marine and brackish compositions and by rainfall over the lagoon itself. There is now a marked tendency for dissolved salts to accumulate in the Southern Lagoon from year to year, with only occasional reversals, (see Fig. 8).

The accumulation of dissolved salts would have been at a slower rate and subjected to more frequent reversals during the time when the lagoon was subjected to regular influx of fresh water at its closed end. Thus, permanently hypersaline conditions have most likely developed only since the cessation of regular flow from the creek. Between 1920 and about 1948, when the creek last flowed, the Southern Lagoon waters may have been hypersaline for long periods of time, interrupted by occasional winters during which lower salinities followed flow from the creek. Prior to 1920, hypersaline conditions were probably much more frequently and effectively diluted as a result of more frequent flow from the creek. None the less, the salinity range in the area south of Cattle Island was within higher values than that in the area north of the island. This is indicated by the distribution of large scale serpulid activity, and perhaps, by the greater thickness of aragonite-rich muds containing Faunule A in the area south of the island.

The environmental change marked by the appearance of aragonite and Faunule A may have been a long-term result of the events which initiated the restricted lagoonal conditions or it may have been partly or wholly due to more recent events. In the Stony Well Basin, this change has probably taken place since 1920 A.D. as a result of artificial alterations of the regional drainage pattern. In the area to the south of the island, the effects of the environmental change are found at a greater depth below the sediment

surface, suggesting that there the change is of greater age. In this case, the increasing range of salinities may have been caused by the gradual silting up of the Hell's Gate Passage or other restrictions on water circulation. The Recent dunes in the vicinity of Pelican Point have encroached on the lagoon and the channel connecting the lagoon to the ocean. It is not known when this encroachment took place, but the wide sand bars associated with the now largely stationary dunes have greatly reduced the width of deep water leading into the lagoon. This has probably affected the entry of both sea and river water to the lagoon and may have lessened the seasonal dilution of Southern Lagoon water indirectly by its effect on the waters of the Northern Lagoon. The construction of reservoirs on the River Murray has reduced the amount of water flowing down the river at times of strong flow and may have recently reduced the amount of river water entering the Southern Lagoon.

3. Evidence from Encrustations.

The environmental changes indicated by the encrustations described previously (see page 152) supplement the record of changes shown in the sediment sequence.

(1) Bryozoan encrustations.

Although the bryozoan encrustations cannot be precisely fitted into the sequence of events shown by the unconsolidated sediments, they can be approximately placed. The encrustations formed after the main phase of erosion

had produced the platform areas, for they cover many of the remnant outcrops of kunkar and aeolianite. The secondary lithification of the encrustations followed the extinction of the bryozoan organisms and took place during the phase of restricted lagoonal conditions. However, much or all of the lithification took place before the appearance of serpulid colonies in the Southern Lagoon.

It is most likely that the bryozoan encrustations were formed during the sheltered marine phase. The extinction of the organisms probably resulted from a number of factors associated with the development of the restricted lagoonal phase (see page 155) and was probably one of the earliest effects of the restriction of lagoon-ocean connections.

(ii) Serpulid encrustations.

Serpulid encrustations developed in the Southern Lagoon north of Cattle Island after the commencement of lithification of the bryozoan colonies, i.e. after the development of the restricted conditions. The Northern Lagoon, particularly in the vicinity of the River Murray, was probably similar to the present environment throughout the history of the lagoon. It is likely that serpulids migrated southwards from that region as the near normal marine conditions in the Southern Lagoon were replaced by more variable conditions similar to those of the estuarine Northern Lagoon. The southward extent of permanent colonies forming large encrustations was probably limited by the development of salinities above those which the

organisms could tolerate in the lagoon south of Cattle Island. The serpulid colonies of the Stony Well Basin were probably formed during the estuarine sub-phase of the Southern Lagoon, for serpulids are at present found in association with Faunule B in the Northern Lagoon.

The extinction of the colonies on the Southern Lagoon took place after the advent of European civilisation to the region. It may have been a result of the cessation of regular flow from Salt Creek, for this event has had the effect of raising the salinity range of the waters of the Southern Lagoon. Extinction of the colonies would probably follow the raising of the salinity range to include chlorosities above about 30‰, the maximum that the organisms can tolerate.

Thus, the recent extinction of the serpulid colonies suggest that the location of the 30‰ isochlor line for summer has shifted northwards from the vicinity of Cattle Island within the last forty years or so. More recently, the southern limit of permanent serpulid growth has shifted to the vicinity of Boundary Bluff, suggesting a continuation of the northward shift of the 30‰ summer isochlor line. This may be an indirect result of the rising salinity range of the Southern Lagoon, for much water from the latter runs into the Northern Lagoon each spring and contributes to the seasonal rise in salinity there.

4. The Cause and Age of the Regression.

The emerged lagoonal deposits along the shores of the Coorong and the emerged ocean beach deposits along parts of the western side of Youngusband Peninsula were probably deposited contemporaneously. Owing to the relatively close connection between the lagoon and the ocean during the phase of sheltered marine sedimentation, the higher water level in the lagoon almost certainly signifies that the sea level of that time was higher, relative to the land surface, than the present sea level. The regression which led to the stranding of the emerged deposits may have been caused by either an eustatic lowering of sea level or isostatic uplift of the region containing the emerged deposits.

Recent high sea levels at elevations above the present sea level have been suggested by several Australian authors, notably Sprigg (1952 a and b) and Fairbridge (1960 and 1961), but such oscillations have been refuted by Shepard (1964) and others. In the vicinity of Adelaide, sequences of Recent sediments showing two separate marine horizons have been described by Howchin (1886, 1912, and 1919), Aitchison and other (1954) and Porter (1961). This succession has been regarded as indicating two Recent eustatic high sea levels, called by Sprigg (1952a) the Anadara and Osborne high sea levels. Porter (1961) considered that these two levels in a subsurface section along the shores of Saint Vincent's Gulf were caused by a combination of eustatic and isostatic movements.

Sprigg (1952a) correlated the emerged deposits of the South East District with the Anadara and Osborne high sea levels. He considered that during the older Anadara high sea level, about 4000 to 7000 years B.P., the sea level stood about 20 to 30 feet above present sea level. During the younger Osborne high sea level, about 1000 to 2000 years B.P., sea level rose to about 5 feet above present sea level. On the edges of the Adelaide Plains, Porter (1961) correlated a lower marine bed, on faunal grounds, with Sprigg's Anadara high sea level. Shell material from this bed gave a carbon-14 date of 6350 ± 153 years B.P. (Porter, personal communication), which is within the age estimated by Sprigg (1952a) for the Anadara high sea level.

Sprigg (1952a) considered that the shelly sands of the Coorong, referred to in this investigation as the sediments of the sheltered marine phase, were deposited during the Osborne high sea level. However, the Coorong area does not fully support the above pattern of Recent sea level fluctuations, as there is evidence for only one sea level higher than the present sea level. The emerged deposits of the Coorong area indicate a water level about 5 feet above the present high water level of the lagoon, which is close to sea level. But there is no evidence of a second, higher strandline, either in the form of eroded dunes or emerged shell deposits to correspond with deposits of the Anadara high sea level in the South East District. In an environment such as that adjacent to the lagoon, a higher water level

should leave some trace of its existence. It may be that the Anadara deposits of the South East are older than the Recent, or they have been subjected to uplift after their deposition within the Recent. In either case there is no evidence in the vicinity of the lagoon of an undoubted eustatically controlled high sea level to correspond with the Anadara high sea level deposits of the South East District.

The emerged lagoonal deposits may well be contemporaneous with other emerged deposits in the South East ascribed by Sprigg (1952a) to the Osborne high sea level. However, there is some doubt as to whether the regression in the Coorong region was caused by an eustatic fall in sea level and the emerged deposits are undoubtedly older than the age of 1000 to 2000 years B.P. postulated by Sprigg (1952a) for the Osborne high sea level, (see page 206).

The encroachment on the northern half of Younghusband Peninsula by the Southern Ocean suggests that there may have been some movement in the underlying rocks within the Recent. This also casts some doubt on the stability of the region occupied by the Southern Lagoon. Sprigg (1952a) considered that there was a shallowing of the Coorong Lagoon towards the south and that this was due to a progressive downwarping to the north. The present investigation has shown that there is not a regular or progressive change in the depth of the lagoon floor. However, von der Borch (1962) reported a northward decrease in the elevation of the surface

of the mud flat which surround the lakes in the southern end of the Coorong. This does suggest that there has been a tilting downwards to the north, which would be in keeping with the regional pattern of Pleistocene land-warping movements described by Sprigg (1952a).

Because of the possibility of tectonic instability in the Coorong region during the Recent and the absence of indications of Recent eustatic oscillations in other parts of the world, as reported by Shepard (1964), it is considered that the emerged lagoonal and ocean beach deposits of Recent age near the Coorong are more likely to have been stranded by a slight tectonic uplift than by a eustatic lowering of sea level.

The age of the regression cannot be precisely determined on the evidence available. However, muds from two of the lakes in the southern part of the Coorong have been dated by the carbon-14 method, (Skinner and others (1963) and von der Borch and others (1964)). The formation of the dated sediments followed the isolation of the respective lakes from the Coorong Lagoon which took place during or after the regression.

The lake considered by Skinner and others (1963) is near the southernmost end of the Coorong, towards the end of the chain of lakes called the "younger" lake series by Alderman and von der Borch (1963). A sample taken at 19-20 inches below the lake floor and about 10 inches above the base of the lake muds gave a date of 3000 ± 600 years B.P.

(Skinner and others (1963)). If the average rate of deposition for the topmost 20 inches of mud were maintained during the deposition of the lowermost 10 inches, the oldest lake sediments in this lake would be about 4000 years old. Thus the isolation of this lake took place about 4000 years B.P., and the regression commenced at some unknown time prior to this date.

Because of its location, the lake sampled by von der Borch (von der Borch and others (1964)) was probably separated from the lagoon after the lake sampled by Skinner. The oldest date obtained was 2030 ± 250 years B.P., which is probably long after the commencement of the regression.

5. The Relationship between the Lagoon and other Carbonate Deposits of the Coorong.

During the phase of sheltered marine sedimentation, the Coorong appears to have been a single, fairly uniform body of relatively shallow sea water, for sediments containing Fauna 1 are found throughout its length. The marine regression separated the Coorong into a number of parts in which different varieties of sediments have since accumulated in response to local environmental controls. The isolation of the various lakes within the Coorong followed the regression, so that the deposition of the carbonate muds in these lakes must have been contemporaneous with the restricted lagoonal phase of sedimentation of the main lagoon.

The "older" lakes of Alderman and von der Borch (1963), i.e. those to the east of the Ephemeral Lagoon, were isolated from the lagoon early during the regression, for kunkar barriers between the lakes and in the channel which connects the lakes to the lagoon are at an elevation of about 5 feet above the lagoon high water level, i.e., close to the maximum height of lagoon water indicated by emerged lagoonal deposits. Since the regression and the isolation of the lakes, three assemblages of carbonate minerals have been deposited - ordered dolomite, dolomite and magnesite, and aragonite and hydromagnesite - depending on the physical and chemical conditions of the various lakes, (von der Borch (1962) and in press).

The "younger" lakes of Alderman and von der Borch (1963), stretching south of the Ephemeral Lagoon, are considered by these authors to have been more recently separated from the lagoon. In these lakes, magnesian calcite or magnesian calcite and dolomite have been deposited. von der Borch (1962 and in press) considered that the lakes were formed by the successive stranding of shallow stretches of the lagoon by drift sands and carbonate mud, so that the oldest lakes of this series are at the southern end of the Coorong. The ages presented by Skinner and others (1963) show that the separation of the lakes near the southern end of the series took place some time prior to 4000 years B.P. Although the lake from which von der Borch sampled carbonate muds for dating is close to the lagoon, the local topography suggests

that this lake was separated from the lagoon before some of the lakes further south were isolated, so this lake is not one of the most recently separated lakes.

von der Borch (1962) and Alderman and von der Borch (1963) considered that the Samphire covered mud flats adjacent to the Ephemeral Lagoon and surrounding the lakes to the south were originally deposited as mixed aragonite and magnesian calcite muds within an extension of the Ephemeral Lagoon and that the aragonite has since inverted to calcite, with magnesium being incorporated within the calcite lattice. There is a possibility that these muds may have been deposited as magnesian calcite alone. The mud sequence of the main part of the lagoon shows that there was a period during which magnesian calcite formed the predominant variety of calcium carbonate deposited there, and the same may be true of the Ephemeral Lagoon at that time. However, the very high calcareous content of the muds in the mud flats suggests that a high proportion of locally formed carbonate was incorporated in these deposits, for much of the mud sequence in the main part of the lagoon is not as highly calcareous. In the shallow-water environment in which this carbonate would form, aragonite-rich muds may have been produced at the same time that calcite was the predominant variety of calcium carbonate formed in the deeper waters of the main lagoon.

The compositional differences between the muds of the different lakes and between the lakes and the lagoon have

resulted from the segmentation of the Coorong into depositional sites which receive water from different sources. The waters of the lakes are derived principally from rain, localized surface run-off and ground water intake. As a result of local variations, the compositions of the dissolved salts in the lakes show slight differences which have been correlated with the compositional differences of the lake muds - von der Borch (1962 and in press). The lagoon derives its water from rainfall over the lagoon, the Southern Ocean and the River Murray. The dissolved salts in the lagoon water are almost entirely derived from the ocean, so that lagoon water is essentially sea water which has been subjected to dilution by river water or concentration by evaporation.

According to von der Borch (1962), the assemblage aragonite-magnesian calcite is invariably associated only with the main lagoon and aragonite is absent in all the lake sediments along the Coorong to the south-east of the lagoon. Some of these lakes precipitate magnesian calcite alone, but no explanation could be offered for the non-appearance of aragonite. The present investigation has not led to the solution of this important problem. All that can be added to the previous discussion of von der Borch is that the appearance of aragonite in the main lagoon has been a relatively recent event, associated with an increase in the salinity range and the maximum salinity attained during the annual compositional cycle of the lagoon waters.

<u>SEDIMENTATION PHASES IN THE WHOLE LAGOON.</u>	RESTRICTED LAGOON PHASE. (FAUNA 2)		SHELTERED MARINE PHASE. (FAUNA 1)	EMERGED LAND SURFACE.	
Main sediment types	Muds, microcoquina and little sand.		Sands and shell beds.	Kunker, sands.	
<u>SOUTHERN LAGOON.</u> Organic remains. Encrustations. Mineralogy of carbonate muds. Emerged lagoonal sediments. Emerged ocean beach ridges. Relative sea level changes. Separation of Coorong lakes from the lagoon.	HIGHLY HYPER-SALINE SUB-PHASE.	ESTUARINE SUB-PHASE.	SHELTERED MARINE PHASE.		
	Fauna 2		Fauna 1		
	Faunule A		Faunule B		
			Serpulids		Bryozoa
	Magnesian calcite				
	Aragonite				
			Mud unit	Shell unit	Shelly sands
					Sands
			? Regression		Transgression
			"Older" lakes		
		"Younger" lakes			
		circa 4000 yrs. B.P.		circa 6000 yrs. B.P.	

Relative Time, not to scale.

Figure 13.

Summary of the sedimentation phases and related events in the Coorong area.

This was accompanied by an increase in the proportion of calcium carbonate in the lagoonal muds, which suggests that the precipitation of aragonite in the lagoon was induced by a higher rate of carbonate precipitation. However, the salinity range shown in lakes precipitating magnesian calcite alone extends to values far higher than those of the lagoon waters, so the answer of this problem is still not known.

6. Summary.

The history of the lagoon's development, as recorded in the sediments and organic remains, shows an increasing degree of isolation between the lagoon and the ocean. This has resulted in an increasing degree of restriction on water circulation, affecting both the inflow of water from external sources and longitudinal mixing within the lagoon.

In the earliest known stage of the lagoon's history, the lagoon and the ocean were closely connected and efficient exchange of water between these two bodies allowed only a relatively slight seasonal variation in water composition. The lagoon was then a sheltered body of sea water, probably affected to a slight degree by fresh water flow from Salt Creek and the River Murray and by evaporation during summer.

Following or accompanying a marine regression, probably caused by tectonic uplift, the lagoon became increasingly isolated from the ocean and the exchange of water between these two water bodies was restricted. As a result, seasonal variations in the rate of fresh water inflow and

in the rate of evaporation of lagoon water produced wide fluctuations in water compositions. This effect was accentuated by limitations imposed on longitudinal water circulation by the topography of the lagoon floor. The latter led to the differentiation of the lagoon into two parts showing distinctly different depositional environments. This differentiation may have been assisted by the silting up of the Hell's Gate Passage, following the loss of frequent tidal movements through the lagoon, and other limitations on the entry of water to the lagoon.

The Northern Lagoon developed estuarine characteristics and formed a site for the deposition of mainly argillaceous muds. The Southern Lagoon also showed estuarine characteristics for a while, but conditions there were suitable for the precipitation of a significant amount of magnesian calcite. Later, a further environmental change occurred, leading to the deposition of calcium carbonate at a higher rate and aragonite replaced magnesian calcite as the principle form of carbonate precipitated. This change was closely associated with a faunal change, with Faunule A replacing Faunule B. These changes indicate an elevation of the salinity range shown by the waters of the Southern Lagoon during the annual cycle of water composition and the attainment of higher salinities. This increase indicates a reduction in the ability of fresh or marine waters to dilute the waters of the Southern Lagoon. It may have been a result of either a slowly increasing restriction

on longitudinal water circulation or may have been caused by a relatively sudden restriction in one of the narrow sections of the lagoon. In the Stony Well Basin, the salinity increase has taken place within historical times and is probably due to the cessation of fresh water flow from Salt Creek. This artificially induced event may have only hastened a natural evolution of increasingly hypersaline conditions in the Southern Lagoon. This, in turn, may be affecting the Northern Lagoon.

The regression which caused the development of the restricted conditions in the present lagoon area led to the total emergence of a large portion of the former Coorong Lagoon. In the emerged areas, ephemeral lakes were formed within depressions in the Pleistocene dune topography and in the interdunal depression east of the Recent dunes. These lakes formed sites for the deposition of a variety of carbonate muds, the composition of which differs from the composition ^{of} contemporaneously produced carbonate muds of the main lagoon.

CONCLUSION.

CONCLUSION.

The sediments of the Coorong Lagoon are characterized by the presence of features which are indicative of a number of major depositional environments. As well as reflecting environmental conditions in the present lagoon, the sediments reflect the lagoon's past history and the proximity of strandline deposits which have accumulated along the shores of the Southern Ocean.

Sand-sized sediments show characteristics inherited from their various sources. Quartz and calcareous grains derived from the Pleistocene dunes show evidence of abrasional processes which took place prior to their final accumulation in the dune deposits. They also show evidence of corrosion which has taken place within the dunes prior to the reworking of the sands by the lagoon waters. Sands derived from the Recent dunes, particularly the calcareous grains, show evidence of abrasion which has not been caused by sedimentation processes within the lagoon. Within the lagoon itself, little abrasion of sand grains is proceeding. Shell material is being rounded only in strandline areas and most grains of lagoonal origin have angular edges. However, corrosion of carbonate grains is proceeding within the lagoon.

The organic remains which have accumulated within the lagoon are indicative of three distinct depositional environments. Shells and other organic debris have been derived from:

- (i) open ocean beach faunas of both Pleistocene and Recent age;
- (ii) a sheltered, near-shore marine fauna; and
- (iii) the flora and fauna of the lagoonal environment.

The organic remains of the present lagoonal environment are characterized by the presence of relatively few species which are abundant. The species which are characteristic of the present conditions are the mollusca Coxiella confusa and Diaphoromactra versicolor, and the foraminifera Ammonia beccarii, which is characteristic by virtue of its abundance and its predominance among the foraminifera. The oegonia of the plant Chara may also be characteristic of the lagoonal environment, but specific identification of the forms present is required. The ostracods of the Species A association and the ostracod, Species C, are the principal organisms characterizing the subdivision of the lagoonal sedimentation into what have been called the estuarine and the highly hypersaline phases. These organisms, too, may well be indicative of the lagoonal environment, but again specific identification is needed.

The detrital sediments of the Northern Lagoon are similar to those which could be expected in some true estuaries. Their only outstanding feature is the distribution pattern of the mud sediments and their relationship with the adjacent aeolian deposits. As sedimentary rocks, these lagoonal sediments could well be interpreted as an accumulation which was deposited within

an estuary of the hypersaline type, such as those found at the mouths of streams subjected to periodic flow in warm or hot climates.

The muds of the Southern Lagoon, however, are more strongly indicative of an isolated lagoonal environment. The mineralogical association aragonite-magnesian calcite appears to be related to the development of highly hypersaline conditions in evaporating sea waters. However, it is likely that post-depositional changes in the carbonate mineralogy during recrystallization and lithification of the muds would eventually replace this assemblage of two relatively unstable minerals. The highly calcareous nature of the muds, when coupled with their chemical origin, indicates a low rate of supply of detrital material and the development of physical and chemical conditions suitable for the precipitation of calcium carbonate.

In the Coorong Lagoon, carbonate precipitation has been induced by moderately high pH and water temperatures and by high salinities. Although carbonate muds of similar composition have been recorded in less extreme and more open marine environments, such as the Bahaman deposits described by Cloud (1962) and others, the combination of such sediments and the organic remains of the Coorong Lagoon is distinctive. A further distinctive feature is the elongate shape of the mud accumulation and its proximity to aeolian sand deposits.

The deformation associated with the dune-mud contacts,

although rare at the present time, could become more widespread as the dunes encroach further onto the lagoon area. The folded muds are partially dried after their uplift and become more coherent, so it is possible that the outlines of the long folds could be preserved within the sediment sequence. The form of the folds is distinctive by reason of the regularity imposed by the unique relationship between the advancing dune-mass and the thick mud sequence.

In many rock sequences, the presence of algal-stromatolites associated with shallow-water carbonate deposits has been interpreted as indicative of a lagoon-like environment. In the Coorong Lagoon, it appeared that a similar association could have been present. However, it is considered that the laminated columnar and dish-shaped bodies along the shores of the lagoon have been formed within the weathering profiles of the Pleistocene dunes and that they are not genetically related to the lagoonal environment.

The Coorong Lagoon marks a transitional zone in which the non-marine, carbonate-producing environment of the Coorong lake system grades into the marine environment of the Southern Ocean. Within the lagoon, environmental conditions progressively become less favorable for the development of carbonate-rich muds as the influence of the River Murray and the Southern Ocean increases. Under the influence of these two water-sources, the lagoon shows a northward gradation from hypersaline lagoonal conditions in which carbonates form a large percentage of the

contemporary mud sediments to estuarine conditions in which detrital sedimentation is predominant.

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APPENDIX A

Grain size distribution curves and tabulated
characteristics of sands.

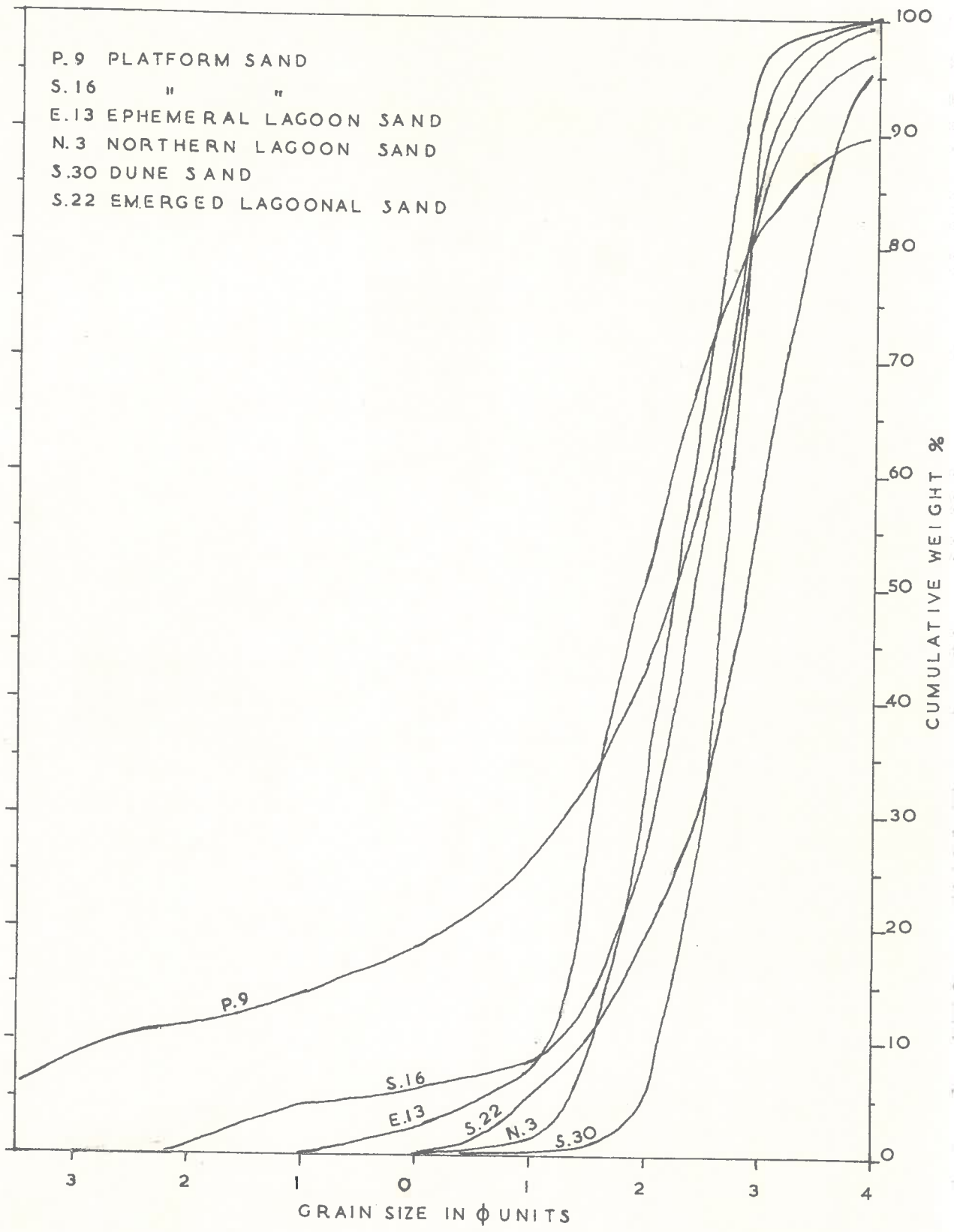


FIGURE 14.

GRAIN SIZE DISTRIBUTION CURVES.

TABLE 3.

Characteristics of dune sands.

a. <u>Recent</u> <u>dune sands.</u>	Sample	M_z	σ_I	Calcium
	No.			Carbonate
				%
	B.11	1.61	1.05	
	B.12	2.61	0.34	35
	S.29	2.61	0.34	41
	S.30	2.52	0.44	37
	P.14	1.73	0.71	47
	P.15*	2.29	0.61	40
	P.16	1.40	0.28	60
	P.17*	1.35	0.62	50
	P.18	2.51	0.44	

* These two samples are reworked dune sands at the lagoon shore-line.

b. <u>Weathered</u> <u>Pleistocene sands.</u>	Sample	M_z	I	Clay +
	No.			Silt %.
pink sand	P.21	2.56	-	13.0
siliceous sand	P.22	3.17	-	11.3
siliceous sand	CI.6	-	-	26.4
siliceous sand	SW.10	2.56	0.58	4.62

TABLE 4.

Characteristics of lagoonal sands.

a. <u>Platform sands</u> <u>Southern Lagoon.</u>	Sample No.	M_z	G_I	Calcium Carbonate %
	S.1	2.03	0.37	1
	S.3	0.69	1.50	
	S.5	1.45	1.56	22
	S.9	1.33	1.70	
	S.13	1.65	1.55	
	S.14	0.71	1.02	
	S.16	2.43	0.92	32
	B.6	1.64	0.61	50
	P.5	3.09	0.75	
	P.6	2.56	0.42	43
	P.9	1.88	1.77	21
	P.12	1.19	0.84	36
	C.47,0-6"	0.68	1.18	95
	C.85,0-2"	2.46	0.45	11
	C.85,28-31"	2.02	0.81	30
	C.88,18-24"	1.15	1.61	
	C.92,43-46"	1.57	1.37	80
b. <u>Ephemeral</u> <u>Lagoon.</u>	E.13	1.90	0.35	42
	E.18	2.17	-	51
	E.20	2.60	0.52	44
c. <u>Northern Lagoon</u> <u>sands.</u>	N.3	2.10	0.52	
	N.4	2.19	0.59	
	N.5	2.18	0.44	
d. <u>Emerged lagoonal</u> <u>sands.</u>	S.22,36-42"	2.72	0.88	
	S.23,24-36"	3.18	0.47	
	H.1	2.20	0.80	

APPENDIX B

Tabulated summary of X-ray diffraction photographs.

The ration "aragonite : calcite" refers to the relative intensities of the strongest reflections given by these two minerals. The abbreviation "calc." indicates that calcite is either the only or the predominant calcareous mineral present. The following symbols have been used :

- X denotes that the appropriate pattern is strongly shown;
- x denotes that the pattern is moderately strong;
- f denotes that the pattern is weak or faint.

TABLE 5.

Composition of muds in the Sphemeral Lagoon.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
E.1	Surf.	X	X	2:1		3.019	6
E.2	"	X	X	2:1	89	3.023	5
E.3	"	X	X	2:1	90	3.028	3
E.4	"	X	X	2:1		3.028	3
E.5	"	X	X	3:1		3.011	9
E.6	"	X	X	4:1		3.011	9
E.7	"	X	X	3:1		3.015	7
E.8	"	X	X	2:1		3.028	3
E.9	"	X	X	1:1		3.015	7
E.10	"	X	X	1:1		3.019	6
E.11	0-1.3	X	X	2:1	85	3.011	9
E.11	1.3-3	X	X	3:1		3.028	3
E.12	4-7	X	X	4:1		3.015	7
E.14	0-1.5	X	X	2:1	88	3.019	6
E.15	0.5-1	X	X	3:1		3.019	6
E.15	4.5-5.5	X	X	2:1		3.015	7
E.17	2-4	X	X	4:1		3.015	7
E.19	1-2	X	X	4:1		3.015	7

TABLE 6.

Composition of muds in the Bul Bul Basin.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (A)	mol % MgCO ₃
(a) Surface samples.							
B.1	Surf.	X	X	2:1		3.007	10
B.2	"	X	X	2:1		3.013	8
B.3	"	X	X	2:1		3.018	6
B.4	"	X	X	2:1	65	3.013	8
B.5	"	X	X	2:1		3.023	5
C.2	0-1.5	X	X	2:1	81	3.013	8
C.20	0-4				74		
(b) Cores.							
C.2	0-1.5	X	X	2:1	81	3.013	8
	12-13	X	X	2:1	84	2.998	13
	16.5-19	X	X	1:1		2.986	17
	19-20	X	X	0.8:1	86	2.986	17
	23-24	f	X	Calc.	82	2.994	15
	40.5-41.5	f	X	Calc.	89	2.982	19
	48-49	x	X	1:10		2.994	15
	53-54	x	X	1:10	76	2.994	15
C.6	6-8	X	X	2:1		3.003	11
	19-21	X	X	2:1		3.013	8
	28-29	x	X	1:5		2.994	15
	29-30.5	f	X	Calc.		3.001	12
	37.3-38.5	f	X	Calc.		2.980	19
	38.7-39.8	X	X	2		2.999	13
	39.4-39.8	X	X	2		3.001	12
40-41.5	X	X	2		2.992	15	

TABLE 7.

Composition of surface muds in the Salt Creek Basin.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
G.23	0-2	X	X	3:1		3.007	10
G.30	0.5-1.5	X	X	1:1		3.019	6
G.40	0-1	X	X	2:1	66	3.015	7
G.62	0-3	X	X	2:1	62	3.011	10
G.60	0-2				58		
G.65	0-3.5	X	X	2:1	53	3.023	5
S.15	Surface	X	X	1:1	52	3.023	5
S.4	"	X	X	2:1	64	3.001	12
S.5	"	X	X	2:1		3.018	6
S.6	"	X	X	2:1		3.010	9
S.7	"	X	X	2:1		3.018	6
S.8	"	X	X	2:1		3.018	6
S.10	"	X	X	2:1		3.018	6
S.11	"	X	X	2:1		3.014	8
S.12	"	X	X	1:2		3.023	5

TABLE 8.

Composition of muds in cores from Salt Creek Basin.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
0.23	0-2	X	X	3:1		3.007	10
	6-7	X	X	3:1		3.003	11
	7-11	X	X	4:1		3.011	9
	18	X	X	4:1		2.994	15
	27-29	X	X	2:1		3.000	13
	33-34.5	X	X	1:1.5		3.004	11
0.30	0.5-1.5	X	X	1:1		3.019	6
	4-6	X	X	2:1		3.019	6
	6-7.5	X	X	1:1		3.015	7
	7.5-8	X	X	2:1		3.015	7
	8-8.5	X	X	3:1		3.028	3
	18-18.8	X	X	3:1		3.023	5
	25-26	X	X	3:1		3.023	5
	31-32.5	X	X	2:1		2.994	15
	34.4-35	X	X	2:1		3.006	10
	39-40.5	X	X	0.8:1		2.994	15
	43.5-44.3	X	X	0.8:1		2.994	15
	44.3-45.6	X	X	1:3		2.994	15
45.6-46.6	X	X	1:5		2.990	16	

TABLE 8 cont.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
C.40	0-2	X	X	2:1	66	3.015	7
	12-13	X	X	3:1	59	3.015	7
	21.6-23	X	X	2:1	76	2.998	13
	33-34.5				72		
	39-41	X	X	1:1	70	2.998	13
	43-45				60		
	46-48				62		
	48-50				58		
	50-51	x	X	1:5	58	2.998	13
	51-52				62		
	52-54				49		
	54-56.5	f	X	Calc.	45	3.002	12
	C.49	46-48				58	
58-60		f	X	Calc.	53	2.994	15
65-68		-	X	Calc.	41	3.015	7
72-72		f	X	Calc.		2.977	20
75-77		f	X	Calc.	47	3.006	10
C.62	0-3	X	X	2:1	62	3.011	9
	6-7	X	X	2:1	60	3.015	7
	20-22	X	X	2:1		2.990	16
	27.5-30	X	X	2:1	63	3.002	12
	37.5-39	X	X	0.8:1	62	3.006	10
	48-50	X	X	1:2	60	2.994	15
	53-55	-	X	Calc.	37	2.998	13
	57.5-60	f	X	Calc.	49	2.994	15
	61.5-64				53		
64-66	f	X	Calc.	50	3.006	10	

TABLE 8 cont.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
O.65	0-2	X	X	2:1	53	3.023	5
	36-38.5	X			62		
	53-55				66		
	55.5-58	X	X	2:1	51	3.003	11
	61-62.5	X	X	1:1		3.013	8
	66-66.5	P	X	Calc.		3.013	8
	72-73					50	

TABLE 9.

Composition of surface muds from the Policeman's
Point Basin.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
C.69	0-4	X	X	2:1	55	3.011	9
C.71	0-2	X	X	3:1	53	3.019	6
C.78	0-3.5	X	X	2:1		3.018	6
P.4	Surface	X	X	1:1		3.028	3
P.8	"	X	X	2:1	51	3.023	5
P.10	"	X	X	2:1	53	3.023	5
P.11	"	X	X	2:1		3.019	6
P.1	"	X	X	2:1		3.023	5
P.3	"	X	X	2:1		3.019	6
P.5	"	X	X	2:1	56	3.028	3
P.7	"	X	X	2:1	40	3.023	5
P.2	"	X	X	1:1		3.028	3
C.77	0-1	X	X	2:1	56	3.028	3
C.76	0-1				59		

TABLE 10.

Composition of muds in cores from the Policeman's
Point Basin.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
C.69	0-4	X	X	2:1	55	3.011	9
	5.5-8				54		
	9-12	X	X	3:1	53	3.023	5
	13-16				52		
	18-21	X	X	3:1	56	3.019	6
	25-27.5	X	X	2:1	50	3.006	10
	27.5-28.5	X	X	1:1	53	2.998	13
	29.8-30.5	X	X	1:1.5	53	2.998	13
	37-39	f	X	Calc.	31	3.011	9
	42-45	f	X	Calc.	36	3.015	7
C.77	0-1	X	X	2:1	56	3.028	3
	6-8				53		
	20-22				51		
	22-24				57		
	28-29	X	X	2:1	43	3.003	11
	30-32	X	X	2:1		3.003	11
	36-37				43		
	38-40				32		
	46-48				42		
	48-53				34		
C.78	0-3.5	X	X	2:1		3.018	6
	16-17				58		
	22-23	X	X	2:1		3.018	6
	24-26	X	X	1:1		3.003	11
	29-31	-	X	Calc.		3.003	11
	33-39				38		
	53-55				46		

TABLE 11.

Composition of muds from the Cattle Island Basin.

Sample No.	Depth (inches)	Arag-onite	Cal-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
C.80	0-3.5	X	X	2:1	52	3.028	3
	9-12	X	X	3:1	44	3.011	9
	31-33	X	X	1:1	36	3.013	8
	44-48	-	X	Calc.	26	3.013	8
	48-50	-	X	Calc.		3.013	8
C.81	0-2	X	X	2:1		3.023	5
	7-8.5	X	X	1:1		3.028	3
	9-12	X	X	1:1		2.998	13
	20-24	f	X	Calc.		3.018	6
C.82	0-4	X	X	2:1	51	3.028	3
	41-48	-	X	Calc.		3.028	3
	52-56	-	X	Calc.	25	3.033	1
C.83	0-2	X	X	2:1	53	3.028	3
	14-18	f	X	Calc.	34	3.018	6
	25.5-32	f	X	Calc.		3.019	6
	33-36				20		
	48-50	f	X	Calc.	34	3.028	3
	56-58	f	X	Calc.		3.033	1

TABLE 12.

Composition of surface muds in the Stony Well Basin.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
C.85	0-2				43		
C.87	0-2	X	X	2:1	51	3.019	6
C.89	0-1	X	X	2:1	46	3.023	5
C.91	0-3	X	X	2:1	38	3.033	1
C.92	0-2	X	X	2:1		3.028	3
C.93	0-2				50		
C.94	0-2	X	X	2:1	46	3.023	5
C.95	0-1.5	X	X	2:1	41	3.028	3

TABLE 13.

Composition of muds in cores from the Stony Well Basin.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
C.87	0-2	X	X	2:1	51	3.019	6
	2.5-3.5	-	X	Calc.	35	3.019	6
	7-8				33		
	11-12	f	X	Calc.		3.011	9
	16-16.5				40		
	19-20	-	X	Calc.		3.015	7
	20-21				35		
	25.5-26.5				27		
	30-31	-	X	Calc.	35	3.023	5
	42-42.5	-	X	Calc.	24	3.028	3
	55-57	-	X	Calc.		3.028	3
	57-59				21		
	C.89	0-1	X	X	2:1	46	3.023
1-2		X	X	2:1	45	3.023	5
2-3		X	X	2:1		3.023	5
3-4					43		
5-8		X	X	1:1	44	3.023	5
12-13.5		X	X	1:2	38	3.018	6
17-20		f	X	Calc.	35	3.003	11
20-24		f	X	Calc.	29	3.023	5
24-26					27		
26-28		-	X	Calc.	27	3.033	1
39-42		-	X	Calc.	38	3.018	6
48-51		-	X	Calc.		3.028	3
53-56					16		

TABLE 13 cont.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
0.90	12-14.5	X	X	1:1	38	3.028	3
	23-26				30		
	29-31	f	X	Calc.	32	2.993	15
	34-35				40		
	35-36				22		
	36-38				28		
	48-51				16		
	60-63	-	X	Calc.	19	3.033	1
	88-89				17		
103-107	-	X	Calc.	16	3.018	6	
0.94	0-2	X	X	2:1	46	3.023	5
	9-11	-	X	Calc.	33	3.013	8
	28-31	-	X	Calc.	19	3.023	5
	40-43	-	X	Calc.	17	3.033	1
0.95	0-1.5	X	X	2:1	41	3.028	3
0.95	8.5-9.5	X	X	1:2		3.028	3
	12-14	-	X	Calc.	32	3.003	11
	16-19	-	X	Calc.	24	3.013	8
	25.5-32	-	X	Calc.	16	3.008	10
	54-58	-	X	Calc.	16	3.028	3
0.96	12-18	f	X	Calc.		3.011	9
	31-34	-	X	Calc.		3.018	6
0.97	39-41	-	X	Calc.		3.023	5
	48-52	-	X	Calc.		3.033	1

TABLE 13 cont.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
0.98	21-24	-	X	Calc.		3.008	10
	28-30	-	f	Calc.		-	-
	31-33	-	f	Calc.		-	-
0.99	4.5-10	X	X	1:1	37	3.028	3
0.99	24-30	f	X	Calc.	22	3.033	1
	36-38	-	-	-		-	-
	39-42	-	-	-		-	-
	44-48	-	f	Calc.		3.028	3
	50-54	-	f	Calc.	18	3.023	5
0.100	12-15	X	X	1:1	28	3.031	2
0.111	6-8	X	X	1:1	31	3.032	2
	18-20	-	X	Calc.	25	3.013	8
	38-38.5	-	X	Calc.	24	3.036	-
	43-47.5	-	X	Calc.		3.023	5

TABLE 14.

Composition of muds from the Northern Lagoon.

Sample No.	Depth (inches)	Arag-onite	Calc-ite	Ratio Arag.: Calc.	Calcium Carbonate %	Calcite d(112) (Å)	mol % MgCO ₃
N.1	Surf.	-	x	Calc.	10	3.032	
N.2	Surf.	-	f	Calc.	7	-	
G.112	0-2	-	x	Calc.	17	3.032	
	5-8				15		
	12-19.5				14		
	49-51				15		

TABLE 15.

Composition of Emerged Lagoonal Muds.

Sample No.	Aragonite	Calcite	d(112) (Å)	mol % MgCO ₃	High Angle Refl.	Dolomite	d(112) (Å)	mol % MgCO ₃	Argil. Clays.
(a) Shell Unit.									
B.7	-	X	3.032		X	-	-	-	-
S.17	-	X	3.032		X	-	-	-	-
B.9	f	X	3.033		x	-	-	-	-
SW.9	f	X	3.038		X	-	-	-	-
(b) Mud Unit.									
B.10	-	X	2.998	13	-	-	-	-	-
S.18	-	X	2.988	17	-	f	-	-	-
S.19	-	X	3.008	10	f	-	-	-	-
S.20	f	X	3.018	6	-	X	2.931	64	-
P.13 0"	x	X	3.002	12	f	-	-	-	-
P.13 12"	f	X	3.006	10	-	-	-	-	-
S.27	-	X	2.998	13	-	-	-	-	-
S.28	-	X	3.015	7	x	-	-	-	-
P.20	-	X	2.998	13	-	-	-	-	-
SW.8	-	X	3.011	9	f	-	-	-	-
SW.7	f	X	3.018	6	-	f	2.940	67	f
S.21	-	X	3.008	10	-	f	-	-	-
HG.1	-	X	2.998	13	-	-	-	-	f

TABLE 16.

d(112) spacings of calcite in kunkar and associated
weathered Pleistocene Sands.

Sample No.	Calcite d(112) (Å)
(a) Kunkar.	
B.8	3.037
S.24	3.029
S.25	3.033
S.26	3.033
CI.4	3.038
SW.4	3.028
SW.5	3.028
(b) Pink Sand and Siliceous Sand Units.	
P.19	3.033
P.21	3.033
CI.1	3.038
CI.1	3.028
CI.2	3.033
CI.3	3.033
CI.3	3.328
SW.1	3.037

TABLE 17.

Mineralogy of shells and other organic deposits.

<u>Coxiella</u> shell (at the surface) :	Aragonite.
<u>Diaphoromactra</u> shell (3 feet below the surface) :	Aragonite.
<u>Ammonia</u> shell (at the surface):	Calcite.
<u>Notospisula</u> shell (living) :	Aragonite.
<u>Notospisula</u> shell (8 feet below the surface) :	Aragonite.
<u>Katylegia</u> shell (at the surface) :	Aragonite.
<u>Flavomala</u> shell (at the surface) :	Aragonite.
<u>Mytilus</u> shell (at the surface) :	Calcite.
Algal encrustation on immersed kinkar outcrop :	Aragonite and magnesian calcite.
Encrustating tubes (see page 124) :	Magnesian calcite.

APPENDIX C

Selected core descriptions.

The following cores have been selected as representative of those collected and used in the construction of Figure 18

CORE C.2

C615



CORE C.2.

Inches

- 0-1.5 Pale grey, sandy, granular mud, with no interstitial matrix between the loosely packed aggregates and grains. Aggregates and grains are well sorted and about 0.1 mm. diameter. Ostracods abundant, Coxiella and ostracod-rich lamina at base.
- 1.5-7 White granular mud, with close-packed and merging grains. Ostracods abundant. Fine fibres common and randomly oriented. Few thick fibres. Grades to:
- 7
7-14.5 Granular mud, loosely packed. Slightly pelletal below 8", pellets common below 13.5". Ostracods rare to common, abundant below 13.5", grading to an ostracod lamina between 14.3 and 14.5". Thick fibres common and sub-vertical between 9 and 10". Few Coxiella below 8". Sharp contact at 14.5".
- 14.5-15.5 Granular mud, partly pelletal at the top. Aggregates close-packed. Ostracods increasing downwards to abundant at 15.5". Sharply defined base.
- 15.5-16.2 Alternating laminae of homogeneous and granular mud, with the aggregates merging. Ostracods common.
- 16.2-18.3 White, loosely packed, granular mud. Ostracods abundant, increasingly frequent below 18", grading to an ostracod lamina at 18.3". Ammonia and Coxiella rare, 1 bryozoan fragment.
- 18.3-19 White, loosely packed, granular mud. Ostracods common and thick fibres common.

CORE C.2 cont.

Inches

- 19-20 Thinly laminated white and pale grey mud, in part showing merging aggregates. Dark green and yellow-green fibre-bearing laminae at 19.2". Ostracods common, flat-lying. Grades down to:
- 20-22.4 White granular mud, aggregates close-packed at top but becoming more loosely pecked downwards, and grading to granular and pelletal mud at 21". Ostracods common, increasing to abundant at 21", and ostracod-rich between 22" and 22.4".
- 22.4-22.5 Pelletal mud.
- 22.5-23.1 Pale grey, homogeneous mud, few slightly darker coloured streaks. Ostracods common and flat-lying.
- 23.1-24 Faintly laminated, finely granular and homogeneous mud and ostracod-rich laminae.
- 24-27 Pale grey homogeneous mud. Ostracods common to abundant and flat-lying, increasing to ostracod-rich below 26.5".
- 27-29.5 Thinly laminated dark grey, greeny-grey and white homogeneous mud, with some granular laminae and few ostracod laminae. Chara eogonia rare in some laminae. Two laminae of fine fibres.
- 29.5-31.5 Very pale grey, faintly laminated homogeneous mud. Ostracods rare and flat-lying. Coziella shells very rare and flat-lying.

CORE C.2 cont.

- Inches
- 31.5-32.5 Faintly laminated, very pale and pale grey finely granular mud. Ostracods common and flat-lying. Few large fibres below 32", flat-lying.
- 32.5-35 Very pale grey, homogeneous mud, ostracods rare. Below 33.5", gradually becomes finely granular, with abundant fragmented ostracod tests. Slightly pelletal at 35". Sharp basal contact.
- 35-36 Homogeneous mud, ostracods absent to rare, grades down to :
- 36-36.9 Homogeneous and granular mud, ostracods abundant. Diatoms rapidly increasing below 36.5", grading to:
- 36.9-37 Diatom lamina, with a few mud aggregates but no interstitial mud.
- 37-37.5 Coxiella-rich mud, with diatoms becoming less frequent downwards.
- 37.5-39.5 Pale grey, loosely packed, finely granular mud. Fragmented ostracod tests abundant. Few Coxiella. Increasingly pelletal below 38.5", with ostracod content increasing downwards to an ostracod lamina at 39.5".
- 39.5-40 Pelletal mud, ostracod-rich, grading down to :
- 40 -40.6 Homogeneous mud, ostracods rare. Ostracods, Coxiella and Diaphoromactra abundant in basal lamina.
- 40.6-42 Pelletal mud, with ostracod content increasing downward to an ostracod lamina between 41.7" and 42"

CORE C.2 cont.

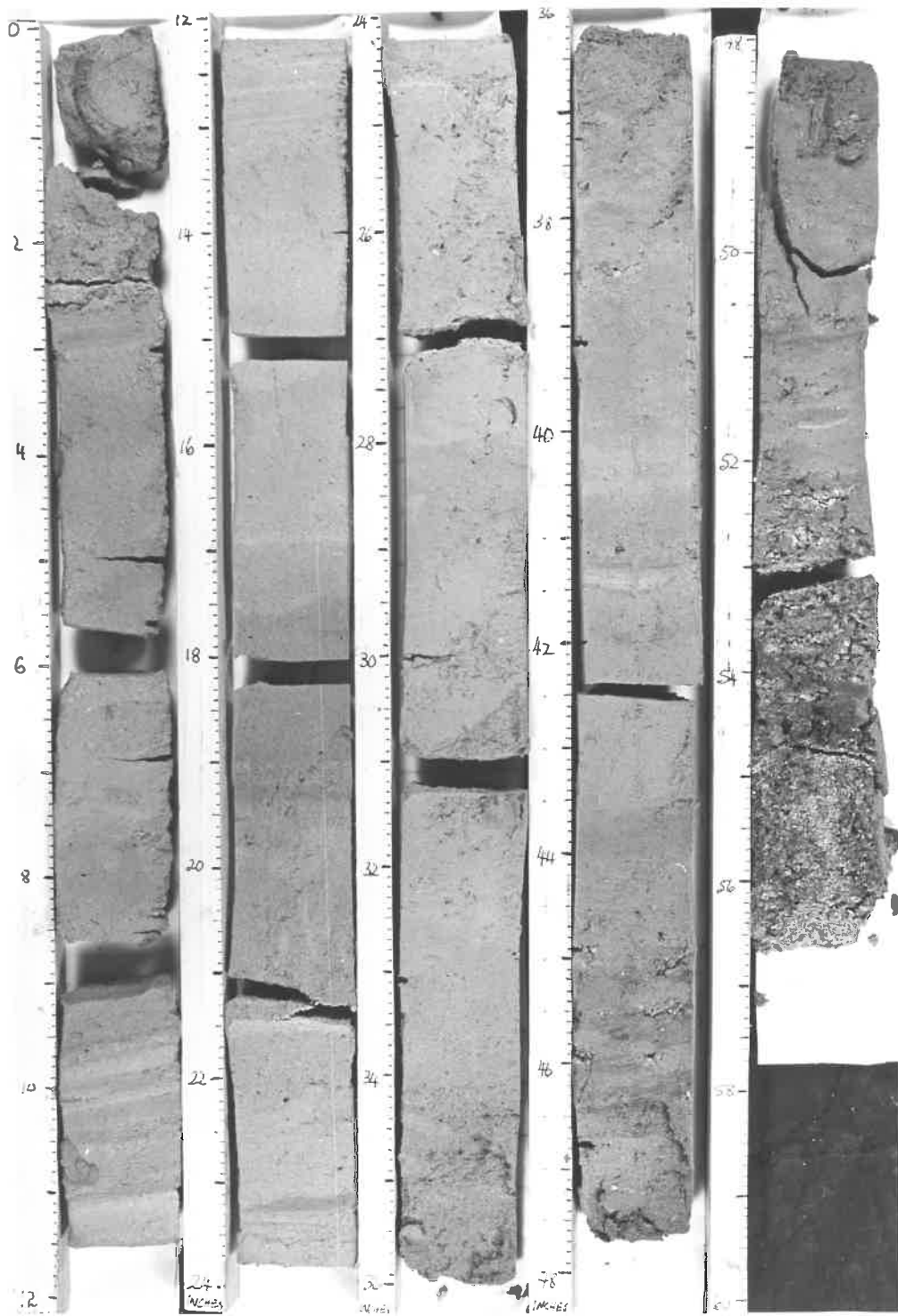
Inches

- 42-42.7 Ostracod-rich homogeneous mud.
- 42.7-43.8 Irregularly laminated greenish grey mud, with flat-lying ostracods abundant in some laminae.
- 43-43.5 Greenish grey homogeneous mud, ostracods abundant, increasing downwards to a basal ostracod lamina.
- 43.5-44.1 Loosely packed very pale grey, granular mud. Ostracods rare, increasing below 43.7" and grading to an ostracod lamina from 44" to 44.1".
- 44.1-45.8 Pale grey homogeneous mud. Ostracods absent to rare. Grades to granular mud with ostracods increasing at 45". Few Coxiella and Diapheromactra below 45". Grades downwards to :
- 45.8-56.4 Ostracod lamina, with fragments of Coxiella and Diapheromactra common, and cogenia of Chara rare.
- 46.4-50 Pale grey, loosely packed pelletal and granular mud. Ostracods abundant. Large fibres common. Few Coxiella and Diapheromactra near 48". Few Ammonia throughout, but rare to common near 48" and below. Cogenia of Chara rare below 48". Shelly, ostracod-rich lamina at 50", with a sharply defined base.
- 50-51.5 Moderately dark grey homogeneous mud, with few fragmented ostracod tests. Sharply defined basal lamina with abundant Coxiella, ostracods and large fibres between 51.4" and 51.5".
- 51.5-54.5 Finely granular, close packed mud. Ostracod tests and fragments abundant.

Inches

- 54.5-55 Lamina of ostracod, Diaphoromactra and Coxiella
microcoquina. Ammonia common.
- 55-56 Granular mud, ostracods abundant. Many shelly
laminæ with Coxiella, Diaphoromactra, and Ammonia.

CORE C.40



CORE C.40.

Inches.

- 0-2.6 Pelletal mud, ostracod-rich at the base and at 0.1", 1.8-2.0", 2.3-2.6".
- 2.6-3.1 Thinly laminated, slightly fibre-bearing mud.
- 3.1-6.2 Very finely granular mud, close packed and merging aggregates. Ostracods common and flat-lying. Ostracods abundant 5.6-6.2".
- 6.2-8.5 Slightly fibre-bearing, homogeneous mud, grading to slightly granular. Ostracods common to abundant and randomly oriented.
- 8.5-9.5 Homogeneous mud, ostracods abundant and flat-lying.
- 9.5-13 Thinly laminated, alternating homogeneous, granular and ostracod-rich mud. Ostracods and fine fibres flat-lying. Rapidly grades to:
- 13-17 Homogeneous and slightly granular mud, ostracods common to abundant. Chara very rare.
- 17-19 Ostracod lamina at 17" above finely granular mud. Ostracods rare and flat-lying.
- 19-21.3 Abrupt change to slightly pelletal, finely granular mud with loose packing. Ostracods common, increasing downwards near the base to:
- 21.3-21.3 Ostracod lamina.
- 21.3-23.3 Slightly granular and homogeneous mud, ostracods common to abundant and flat-lying.
- 23.3-24.5 Faintly laminated mud, with alternating homogeneous and granular laminae.

CORE C.40 cont.

Inches.

24.5-24.7 Ostracod lamina.

24.7-27 Slightly pelletal and slightly granular,
homogeneous mud. Ostracods rare to common.
Very few Coxiella and large fibres. Grades
down to:

27 Ostracod lamina.

27-28 Homogeneous mud.

28-32 Slightly granular and homogeneous mud. Ostracods
rare to common and flat-lying. Few Diaphoromactra
shells, flat-lying.

32-34.7 Slightly pelletal and homogeneous mud. Ostracods
common to abundant, randomly oriented, decreasing
in frequency downwards. Fragments of Diaphoro-
mactra increasing down to microcoquina lamina
34-34.3".

34.7-37 Pelletal mud, pellets 0.2 to 0.25 mm long, no
interstitial mud. Ostracods rare to common.
Shelly below 36" with Coxiella and Diaphoromactra.

37-41 Homogeneous mud, few Diaphoromactra, Coxiella,
and Species C ostracods. Ammonia-rich laminae
below 40".

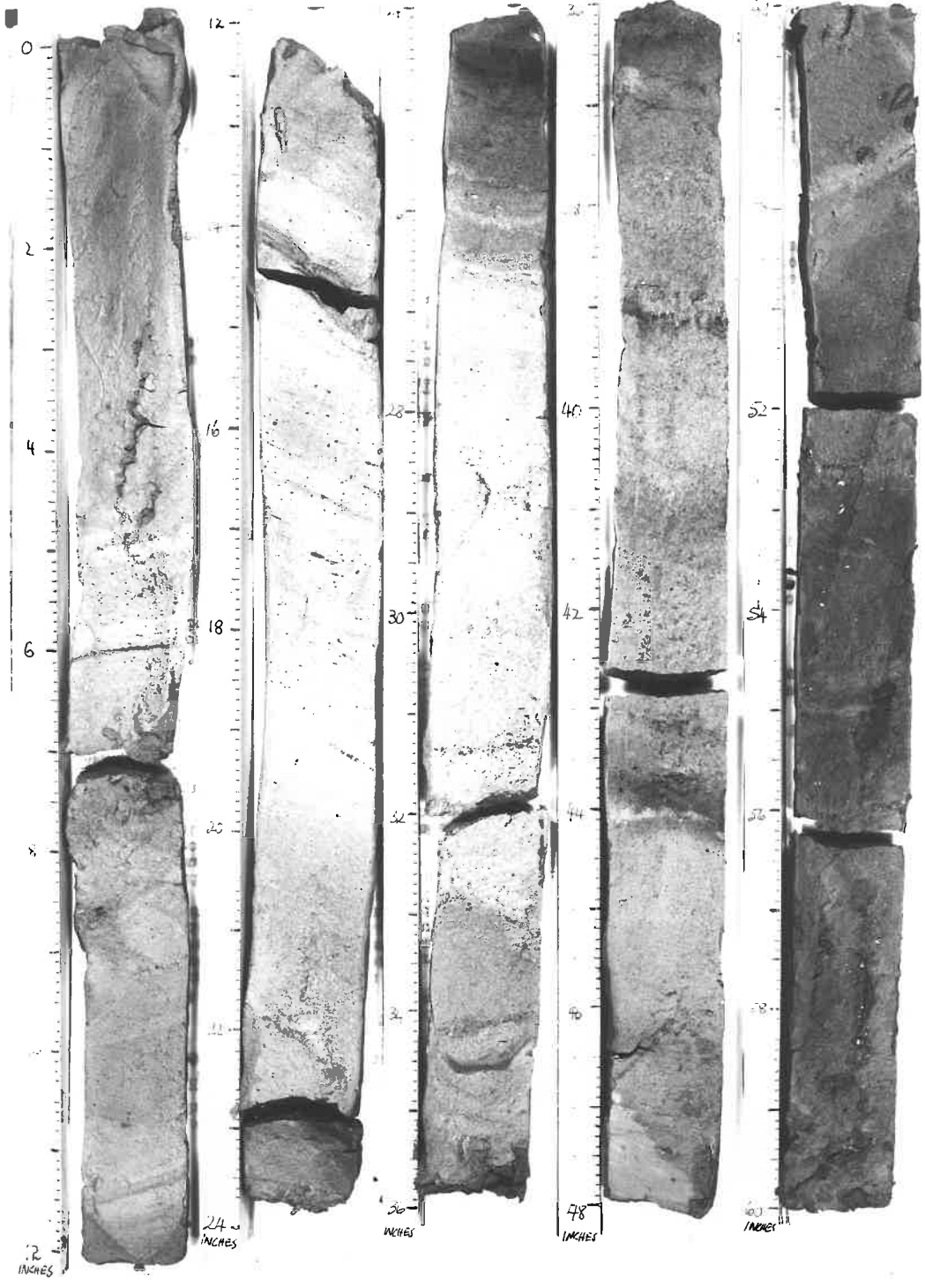
41-41.5 Faintly laminated granular and homogeneous mud.

41.5-45.7 Finely granular mud merging to homogeneous mud.
Sand laminae at 43.5". Diatoms common 44-44.5",
very rare below. Ammonia and Species C ostracods
very rare to rare. Grades down to:

CORE C.40 cont.

Inches.

- 47.5-48 Faintly laminated and banded granular mud, with several Ammonia-rich laminae. Coxiella, Diaphoromactra and Species C ostracods rare to common.
- 48-49 Pelletal mud, few Species C ostracods and Diaphoromactra.
- 49-52 Homogeneous mud, few Species C ostracods, Diaphoromactra and Ammonia. Pelletal mud 50.5-51". Diatoms common near 51.5".
- 52-56.5 Slightly muddy Ammonia-rich microcoquina. Diatom-rich 52-52.5". Coxiella, Diaphoromactra and Species C ostracods common. Few flat-lying fragments of Flavomala below 54".



CORE C.62.

Inches.

- 0-5 Homogeneous mud, ostracods and Ammonia very rare.
- 5-5.8 Granular mud, ostracods abundant.
- 5.8-6 Fine-fibre bearing mud.
- 6-8 Finely granular mud, ostracods common.
- 8-9 Granular and pelletal mud, ostracods common.
- 9-14 Laminated and thinly laminated mud, ostracods very rare; slightly sandy and shelly lamina at 13.5 in.
- 14-14.5 Thinly laminated green and yellow-green fine fibre.
- 14.5-19.5 Thinly laminated mud, slightly fibre-bearing, and partly finely granular. Ostracods and Ammonia common. Both abundant 16 to 17 in., ostracods abundant 18 to 19.5 in. Lamination fades below about 18 in.
- 19.5-20 Very finely granular mud, (aggregates 0.05 mm diam.). Grades down to:
- 20-22 Pelletal and granular mud, ostracods rare.
- 22-22.25 Lamina of ostracods and sand.
- 22.25-23 Homogeneous mud, ostracods abundant.
- 23 Sand lamina.
- 23-24.2 Ostracod rich homogeneous mud.
- 24.2-25 Dark grey finely granular mud, ostracods very rare.
- 25-26.5 Granular and finely granular mud, ostracods very rare, Ammonia rich lamina at 26.5 in. Very faintly laminated.

CORE C.62 cont.

Inches.

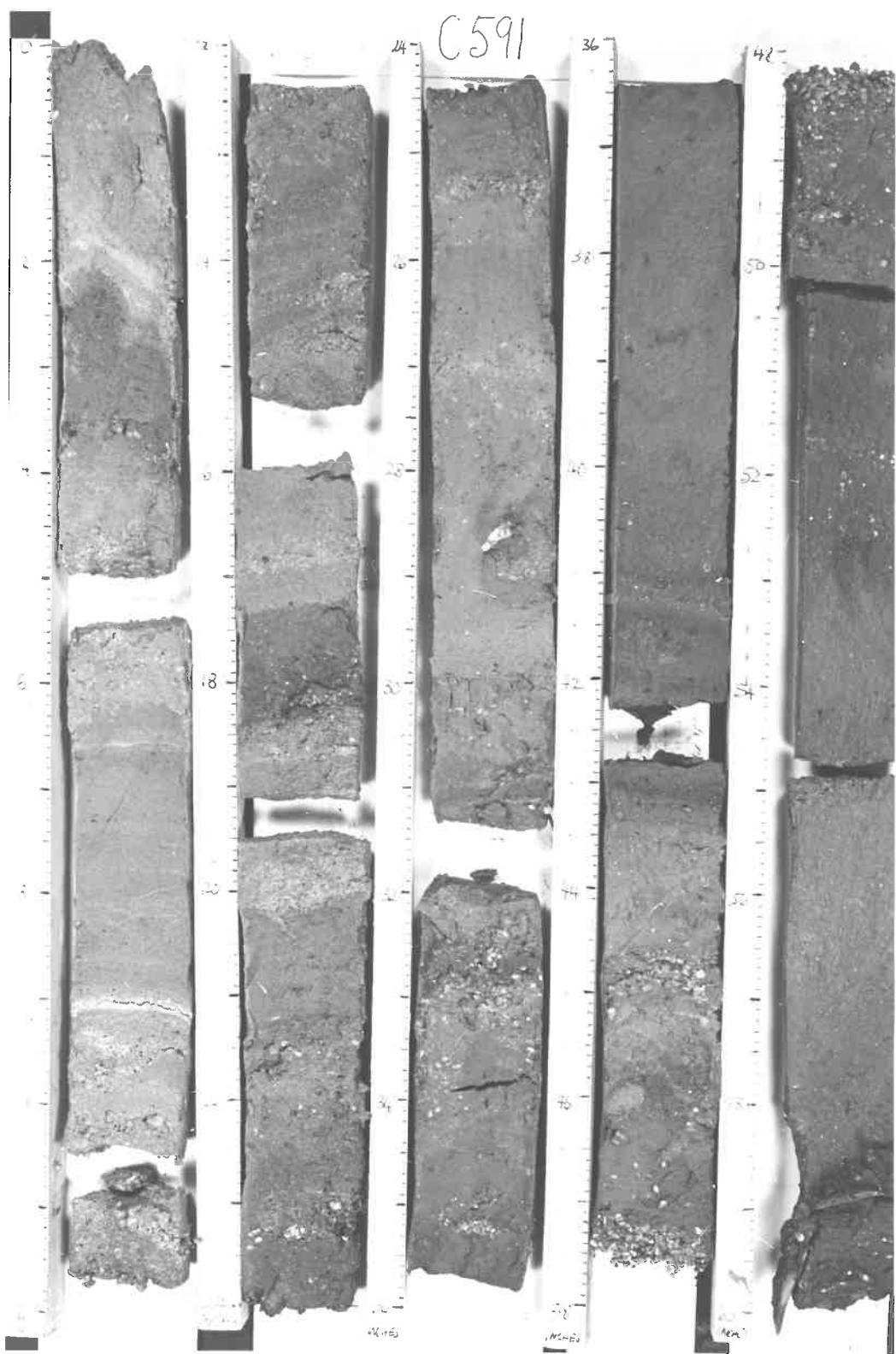
- 26.5-27.5 Laminated and thinly laminated fibre-bearing mud, grades down to:
- 27.5-34.5 Finely granular mud, Ammonia common to abundant. Sharply defined base. Grey-white above 33 in., pale grey below.
- 34.5-36 Faintly and unevenly laminated mud, ostracods common.
- 36-41.5 Very finely granular mud (aggregates 0.03 to 0.05 mm diameter). Grades to pelletal 37 to 37.5 in. then to finely granular (aggregates 0.12 mm diameter) and a few pellets.
- 41.5-42.8 Homogeneous mud diatoms rare at 42 in. Few Ammonia.
- 42.8-44 Faintly laminated, slightly fibre bearing mud, Ammonia very rare.
- 44-47 Granular mud.
- 47-48 Homogeneous mud.
- 48-50 Granular and very finely granular mud, with a sharply defined base and Coxiella at 50 in.
- 50-51.5 Homogeneous and very finely granular mud, very few Ammonia.
- 51.5-52.5 Very finely granular mud, Ammonia rare. At 52.5 in. is a thin lamina of sand, Ammonia tests and "Species C" ostracods.
- 52.5-56.5 Moderately dark grey granular mud (aggregates 0.125 to 0.25 mm diameter). Ammonia rare, but common

CORE C.62 cont.

Inches.

- at 55.5 in.
- 56.5-56.75 Sand and Ammonia lamina.
- 56.75-58.5 Slightly shelly granular mud. Ammonia,
Diaphoromactra and ostracods each rare.
Sandy Ammonia- and ostracod-rich lamina at
58.5 (Microcoquina).
- 58.5-61.5 Homogeneous mud, diatoms rare to common down to
60 in. Ammonia common, "Species C" ostracods
and Coxiella rare to common, increasing shell
content towards the base, with increasing
Coxiella and Diaphoromactra.
- 61.5 Sand lamina with a sharply defined base.
- 61.5-62 Thinly laminated mud.
- 62-62.2 Diatom-rich granular mud.
- 62.2-64 Homogeneous mud, very few shells. Ammonia and
Diaphoromactra microcoquina at 64 in., 65 to
65.5 in.

C591



CORE C. 87.

Inches

- 0-2 Very fine grained, well sorted, sub angular and sub rounded quartz sand. Few Coxiella ostracods and Chara oogonia. Top half inch very slightly muddy. Sharp base.
- 2-2.3 Pale grey homogeneous mud, ostracod-rich. Sharply defined base.
- 2.3-4.5 Medium grey homogeneous mud, ostracods common to abundant. Thin lamina of Coxiella and granular mud at 2.5 in. Few Chara and Diaphoromactra. Slightly granular below 3 in. to 3.5 in. Coxiella lamina at 3.5 in., with a few Chara and Diaphoromactra.
- 4.5-6.3 Above grades down to muddy and slightly muddy microcoquina of fragmented Coxiella, and many Ammonia and white mud aggregates.
- 6.3-6.5 Homogeneous mud, ostracods abundant.
- 6.5-8.9 Faintly laminated mud, predominantly homogeneous, with a few mud aggregates and a few ostracods down to 8 in. Below 8 in. ostracods are common in thin laminae, and thin laminae of white granular mud are found. Granular and ostracod-rich lamina at 8.9 in., grades down to:
- 9-9.1 Granular white mud, no interstitial mud matrix. Coxiella fragments common.
- 9.1-9.8 Slightly muddy ostracod-microcoquina with abundant fine white granular mud. Tests flat lying.

CORE C.87 cont.

Inches.

- 9.8-10 Homogeneous mud lamina.
- 10-15.5 Ostracod microcoquina, with abundant white mud lumps, of very fine sand size. Shell fragments and Ammonia common. Chara oegonia common. Few Coxiella tests. Very little interstitial mud matrix. Less shell and less mud aggregates below 12 in. Ostracod tests flat lying.
- 15.5-16.6 Homogeneous mud, ostracods common.
- 16.6-17 Ostracod microcoquina, pelletal mud at base. Few pellets and mud aggregates in ostracods.
- 17-17.3 Homogeneous mud, ostracods common to abundant.
- 17.3-18.4 Dark grey pelletal mud. Pellets tend to be merging at the top, but clearly differentiated lower down. Gradually increasing content of Coxiella downwards to a Coxiella-rich lamina at 18.4 in. Pellets 0.25 x 0.8 mm. Sharply defined base.
- 18.4-20.2 Ostracod microcoquina, with close packed and flat lying tests, and some fine mud aggregates, but no interstitial mud matrix (mud aggregates are about 0.05 mm diameter).
- 20.2-21.5 Homogeneous mud with many incoherent pellets in small patches. Ostracods rare to common. Coxiella and a few Ammonia at the base.
- 21.5-22.5 Ostracod microcoquina, as 18.4 to 20.2 in.

CORE C.87 cont.

Inches.

- 22.5-23.5 Pelletal mud, and ostracods common, Coxiella and fine fibres common at the base.
- 23.5-24.5 Pelletal mud. Coherent pellets, 0.25 to 0.3 mm long, 0.06 to 0.08 mm wide.
- 24.5-27 Homogeneous mud. A burrow of pellets (which are 0.35 mm long) extends vertically down this bed. The burrow is 0.2 mm wide. Few scattered Diaphoromactra, Ammonia and ostracods. 25.7 in.: an ostracod lamina.
- 27-27.5 Slightly muddy microcoquina of ostracod tests with fine white mud aggregates, and some incoherent pellets.
- 27.5-30 Homogeneous mud. Ammonia common. Scattered Coxiella, Diaphoromactra and Flavomala, all flat lying.
- 30-30.5 Granular mud, pelletal in part, and inside ostracod and Coxiella tests, pellets may be seen, with no muddy matrix between the pellet and the shell wall. Few Coxiella and Ammonia and ostracods very rare.
- 30.5-31.5 Shelly granular and homogeneous mud, pelletal in part. Ostracods common. Ammonia-rich thin lamina at 31 in.
- 31.5-34 Shelly granular mud, no muddy matrix. Ammonia and Coxiella abundant. Diaphoromactra-rich lamina at 34 in.

CORE C.87 cont.

Inches.

- 34-36 Muddy microcoquina of Diaphoromactra and Ammonia.
- 36-40 Homogeneous mud, very few shells.
- 40-41 Pelletal mud, with moderately coherent and incoherent pellets (pellets 0.15 to 0.2 mm long). Few ostracods and very few Coxiella.
- 41-43.5 Faintly laminated homogeneous mud alternating with shelly mud, containing Coxiella and ostracods and ostracod laminae.
- 43.5 Coxiella lamina.
- 43.5-44.7 Granular and diffusely pelletal mud. Few diatoms, Coxiella and Ammonia.
- 44.7-45 Coxiella homogeneous mud.
- 45-46.2 Diatom-rich granular and diffusely pelletal mud, grading to globular pellets, 0.2 mm diameter. Coxiella and Ammonia common. Sharply defined base, rich in diatoms.
- 46.2-47.3 Diatom-rich homogeneous mud, few scattered Coxiella and Ammonia.
- 47.3-48.3 Microcoquina of complete tests of Coxiella, Diaphoromactra and Ammonia, no mud matrix. Many paired valves of Diaphoromactra.
- 48.3-50.3 Shelly homogeneous, diatom rich mud, alternating with disturbed microcoquina layers. Sharply defined base, with the topmost lamina of the underlying bed pelletized.

CORE C.87 cont.

Inches.

50.3-50.6 Slightly granular mud, diatoms rare. Sharply defined base.

50.6-60 Homogeneous mud, diatoms rare, and Coxiella and Ammonia rare down to 53 in. then generally absent.

51.8-52.8 slightly shelly, with Coxiella and Ammonia.

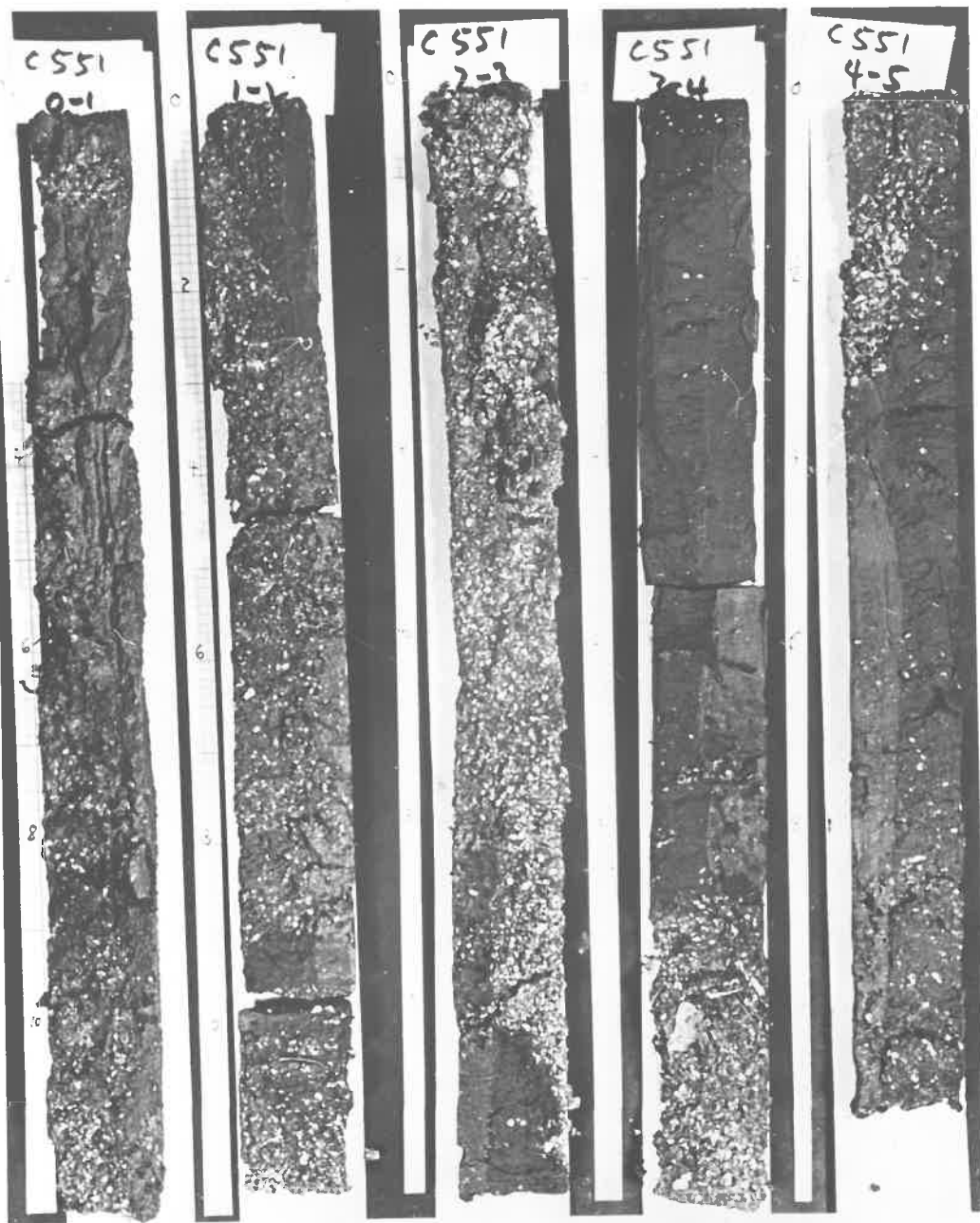
One pellet burrow below 53 in. and one Coxiella shows pellets preserved internally.

55 in. Coxiella and Diaphoromactra microcoquina, with no muddy matrix.

Diatoms rare to common below 58 in.

59 to 60 in. Slightly shelly mud. One pair of Flavomala valves.

CORE G.99



Core C.99.

Inches

- 0-4.5 Homogeneous mud, shelly 1" to 1.5".
- 4.5-34 Muddy micrococquins of complete and fragmented tests of Coxiella, Diaphoromactra and Ammonia.
- 34-45 Slightly pelletal and homogeneous mud. Diatoms abundant to flood 36" to 38" and predominant 38" to 39". Slightly shelly below 43".
- 45-50 Micrococquina, becoming muddy towards the base. Few flat-lying shells and fragments of Flavomala.
- 50-54 Diatom-rich homogeneous mud, few scattered Coxiella Diaphoromactra and Ammonia.
- 54-59 Shelly calcarenite.