STRATIGRAPHIC AND STRUCTURAL DEVELOPMENT OF THE ST. VINCENT TERTIARY BASIN, SOUTH AUSTRALIA

by

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SUMMARY

The St. Vincent Basin in South Australia is a Cainozoic basin which contains sediments of fluviatile and marine origin. On the eastern side of the basin, thicknesses and facies relationships indicate that ancient faults formed the boundaries between high and moderately subsiding areas. Facies relationships suggest that during the Tertiary there were times when movements of blocks adjacent to these faults were independent of one another. The fluviatile sediments are typical of floodbasin deposits and distinctly lack a thick Tertiary conglomerate facies. The absence of this facies and the fine grained nature of marine sediments adjacent to faults indicates that little structural movement occurred on highs separating marine embayments while relative subsidence was the main form of movement in the embayments.

Basal fluviatile floodbasin deposits are typical on the northern side of the basin. Unconformable relationships between sediments of Upper Eocene and Miocene age appear to be widespread in this area denoting a period of very mild uplift during the Oligocene. This movement in part occurred along linear elements but is possibly related to "epeirogenic" movements. Marine sediments intercalated with a lagoonal facies are characteristic of sediments of the western side of the basin. This area also can be subdivided into blocks which at times acted independently of one another.

Upper Miocene - Lower Pliocene and Pleistocene phases of folding and faulting are recognized in sediments on the

margins of the basin. These movements were less intense on the western side ("shield" area) than on its eastern side.

On the eastern side of the basin, fluviatile sediments of Middle Eocene age are present at the base of the Cainozoic sequence, but other fluviatile deposits are younger and are intercalated between marine sediments on the margin of the basin. Still younger fluviatile or lacustrine sediments are found in parts of the Mt. Lofty Ranges. Marine sediments overlap basement in areas of the eastern side of the basin and both on its western and northern sides. Although marine regressions are recognized there is little evidence of reworked foraminifera which suggests that erosion on the margins of the basin was at a minimum. The very mild movements of the rims of the basin, the absence of a major orogeny since the Lower Palaeozoic, thin sequences of Tertiary sediments and movements adjacent ancient faults indicate that the St. Vincent Basin is an intracratonic basin.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University or previously published works by other people, except where due reference is made in the text of this thesis, to best of knowledge and belief.

William J. Stuart

INTRODUCTION

The St. Vincent Basin is a Cainozoic structural basin about 150 miles (240 km) long and 50 miles (90 km) wide, in South Australia (Map 1). The basin is bounded by the arcuate belt of the Mt. Lofty Ranges to the east, Kangaroo Island to the south and Yorke Peninsula to the west. Over 2/3 of this basin is covered by the St. Vincent Gulf, but this does not render it less informative than the many other basins in the world covered by younger deposits. In several areas of the basin most of the Tertiary sequence is revealed in coastal cliffs and there are subsurface data from many land areas. The Tertiary sequences in marginal areas of this basin are paralic sequences, (Glaessner, 1953a). The maximum known thickness of the Cainozoic sediments is about 2,000 feet (610 m) in the Adelaide Plains Embayment. This basin is exceptional because its main depositional axis is situated at approximately a normal angle to the depositional axis of the continental shelf. It is unlike most other basins near the continental margins of the world, such as the California basins which show main areas of accumulation and major faults approximately parallel to the continental shelf. It is in fact, a typical intracratonic basin despite its coastal position. Its shape is partly due to the rejuvenation of ancient faults which at times formed the boundaries between areas of mild relative uplift and subsidence.

Previous Investigations

From the latter part of the last century several geologists have worked on various aspects of Tertiary geology in areas adjacent to the St. Vincent Gulf. Tate (1879-1899), Tepper (1879-1882), Scouler (1879-1882), H.Y.L. Brown (1882-1911) and Howchin (1886-1938) made some of the earliest contributions to our geological knowledge. Several papers by Howchin (1886-1938) recorded many of the known outcrops of Tertiary and Quaternary deposits in areas marginal to St. Vincent Gulf. The references to these authors' works are contained in the Bibliography of South Australian Geology (Teesdale-Smith, 1958).

Only the more important references dealing with the Tertiary stratigraphy and structure of the St. Vincent Basin are mentioned here. This does not belittle the great contribution of stratigraphic knowledge contributed by many workers in the South Australian Mines Department, who have published much stratigraphic and gravity data in Mining Reviews and Quarterly Notes. Specific references to these workers are given in the text.

The extent of geological knowledge accumulated prior to 1911 enabled Howchin (1911) to postulate broad folding preceding differential uplift of peneplained fault blocks to form the Mt. Lofty Ranges. He considered Tertiary sediments downthrown towards the St. Vincent Gulf and indicated the existence of a faulted trough or graben. Benson (1911) concurred with Howchin and produced a model showing fault blocks inferred from the physiography of the Ranges and was the first to consider Kangaroo Island as part of the same tectonic unit. Fenner (1927; 1930) enlarged upon the horst and graben concept and considered both the Mt. Lofty Ranges and Yorke Peninsula as horsts. Both he and Howchin (1913, 1933) postulated a relatively recent age for uplift of the Mt. Lofty Ranges. Fenner (1927) considered that much of the Ranges were covered by Tertiary seas. This was rejected by Glaessner (1953b), Campana and Wilson (1954) and Glaessner and Wade (1958). Sprigg (1942, 1945, 1946, 1961) discussed the structure and geomorphology of parts of the Mt. Lofty Ranges and refined the horst and graben concept by indicating that several small "fault blocks" partly covered by Tertiary sediments were tilted later in the Tertiary and Quaternary. A valuable contribution by

Miles (1952) which did not depart widely from the tilted fault block hypothesis summarized the subsurface geology in areas near the city of Adelaide. References by earlier workers in this area are listed in Miles's work.

In recent years, the Tertiary stratigraphic time-framework is becoming better known through the work of Glaessner, Wade, Ludbrook, Lindsay and Harris. References to these authors are cited in the main text and early references can be found in these authors' works.

Several students working under the direction of Professor Glaessner have contributed to a better understanding of the Tertiary Stratigraphy in areas adjacent to the eastern side of the Gulf. This work has enabled another structural interpretation which is in direct contrast to the tilted fault block concept. Glaessner (1953) considered that ancient faults determined the approximate boundary between rising highs and subsiding lows; that periods of rejuvenated faulting movements on these structures in some areas passively folded the sediments while in other areas beds adjacent to these faults were displaced a few hundred feet. Campana (1955) considered that the Mt. Lofty Ranges were gradually rising during most of the Tertiary, but considered that a reversal of tectonic movement took place during the

Miocene.

A reconnaissance survey of basement, Tertiary and Quaternary rocks on Yorke Peninsula was carried out by Crawford (1965). He postulated many possible structural interpretations but without attempting to evaluate or prove any of them. No great detail on the Tertiary sequences has yet been published. For more complete list of references of authors' works, Crawford (1965) should be consulted.

Purpose of Investigation

It is the purpose of this present investigation to elucidate the relative sense of tectonic movements taking place during the Tertiary by the study of facies and unconformities or basal surfaces of stratigraphic rock units, placing these units in a general basin-wide time framework on the basis of foraminifera so as to determine the migration of depositional environments during successive time intervals during the Tertiary.

Acknowledgements

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The faculty of the Department of Geology at the University of Adelaide offered valuable comments and advice on various aspects of the problem. Special thanks are due to Professor M. F. Glaessner and Dr. Mary Wade, my supervisors, for their assistance throughout this study. I also wish to express my appreciation to Professor R. W. R. Rutland for the facilities made available in the Department of Geology. Other expressions of appreciation go to Dr. Brian Daily and Dr. Brian McGowran for advice and help on various aspects of this study.

I am indebted to Mr. R. C. Sprigg, Beach Petroleum, for making available subsurface samples from various bores, and to Mr. G. Thorpe for permission to collect samples from several percussion bores. Last but not least, I wish to thank my wife, Philippa, without whose hard work this thesis would not have been possible.

CHAPTER I

TECTONIC FRAMEWORK

The arcuate belt of the Mt. Lofty Ranges reaches a maximum height of about 2,000 feet (610 m) although the main arc of the Ranges does not usually exceed 1500 feet (460 m). Its counterparts on Kangaroo Island (Benson, 1911) and in the northern part of Yorke Peninsula rarely exceed 600 feet (180 m). About 40,000 feet (12,000 m) of Proterozoic and Cambrian strata in the Mt. Lofty Ranges constituted the fill of the Adelaide Geosyncline (Mawson and Sprigg, 1950). Archaean (Lower Precambrian) inliers (Map 2) occur near the core of the Ranges (Howchin, 1908; Campana and Wilson, 1954). The Yorke Peninsula "shield" area contains a thin cover of Proterozoic and Cambrian strata and areas of Archaean crystalline rocks (Horwitz and Daily, 1958). A major orogeny occurred during the Lower Palaeozoic and deformation of Proterozoic and Cambrian strata was more intense in the arc of the Mt. Lofty Ranges (Webb, 1958; Daily, 1955; and Forbes, 1966).

Permian glacial sediments located on Yorke Peninsula and on the arc of the Mt. Lofty Ranges record the next depositional event. Their distribution (Map 2) must have been much greater than shown at present and no other local depositional events are known in this area until the accumulation of Eocene fluviatile deposits (Glaessner, 1953b). Campana (1955) suggested that this area was a low but positive area during the Mesozoic, but this is only a local feature as other Tertiary areas bordering the southern portion of the Australian continent contain earlier Tertiary (see McGowran, 1965) and Mesozoic sediments (see Taylor, 1964).

According to Smith (1967), seismic and aeromagnetic surveys over parts of the southern ocean indicate a major lineament immediately south of Kangaroo Island and trending to the west-northwest (Map 1). On the landward side of this lineament he indicates that a thin veneer of probably Tertiary sediments overlies Archaean basement in the southern portion of Spencer Gulf and that this basement is present at greater depths on its oceanward side. This sediment thins northward and eastward, but then thicknesses of Tertiary sediments increase within the St. Vincent Basin, north of Kangaroo Island.

The eastern area of the St. Vincent Basin is divided into a series of arcuate natural areas. Areas of Tertiary deposition are separated by structural highs (Charts 1 and 2) which merge with the Mt. Lofty Ranges proper and are adjacent to rejuvenated ancient fault zones (Sprigg, 1946). The names of these faults are shown on Map 1. The two southern areas containing Cainozoic sediments have been called the Willunga and Noarlunga Basins (Glaessner and Wade, 1958), while the Adelaide Plains Basin (Miles, 1952) comprises the area from the Eden-Burnside Fault zone to the northeastern side of the basin proper (Map 1). The term embayment is used in this study in the sense of a basin-like structural area opening near the present coast to a larger subsiding feature. The geographic names in local use are retained as shown on Map 4 except that I have informally subdivided the Adelaide Plains Basin into component parts. The area between the Eden-Burnside Fault-zone and the Para Fault is referred to as the Adelaide Embayment (Map 4). Most of this embayment is known only in the subsurface except for its northeasterly end.

Most of the stratigraphic evidence for the Adelaide Plains "Embayment" is also located in the subsurface and its northern boundary is arbitrarily defined between Port Gawler and Two Wells as Seedsman (1967) has indicated buried structures and several faults which show only a small vertical separation of

Tertiary beds. This area partly represents a depositional hingeline during part of the Tertiary. . Another unnamed fault (Map 1) is present between this area and the Para Fault but in this area the vertical separation of Tertiary beds is less than 50 feet (15 m). It appears to be a continuation of an unnamed fault near Redbanks (see Kapunda sheet: Dickinson and Coats, 1957). The Adelaide Plains Embayment contains the thickest known accumulation of Tertiary sediments, indicating a more rapid accumulative subsidence during the Tertiary and it is considered the landward end of the main basin. The main depositional axis of this embayment, from available subsurface gravity and data, trends towards the south-southwest (Map 3).

In the Mt. Lofty Ranges, three important areas which are closely related to the St. Vincent Basin and were sites of Tertiary deposition are the Myponga, Meadows and Barossa Valleys (Map 1). The Tertiary sediments in these valleys have been studied by early workers who referred to them as the "Upland Tertiaries". The two southern valleys follow the arcuate trend of the Ranges but the Barossa Valley cuts diagonally across the Ranges in the north. Most of the Tertiary sediments are located in the subsurface in the southern two valleys while better exposures are present in the Barossa Valley. Dalgarno (1960) concluded that either flexure or possible faulting movements occurred in the Barossa Valley during the Tertiary but sediments located near a proposed fault (Coats, 1959) on the southern side of the valley can only be seen in one exposure in the northeastern side of this valley. These areas are not treated in detail in this study, but the ages of the sediments within these valleys are important when interpreting the tectonic development of the Mt. Lofty Ranges (Glaessner and Wade, 1958).

The northern end of the basin is a narrow trough. In style it is closer to the western side (Charts 3A, B, C and D; Map 1) where Tertiary structures (mainly folds) follow the lineation of basement structures, which Johnson (1961) and Sprigg (1965) show to be a series of north-south faults crossed by east-west faults.

CHAPTER 2

STRATIGRAPHY

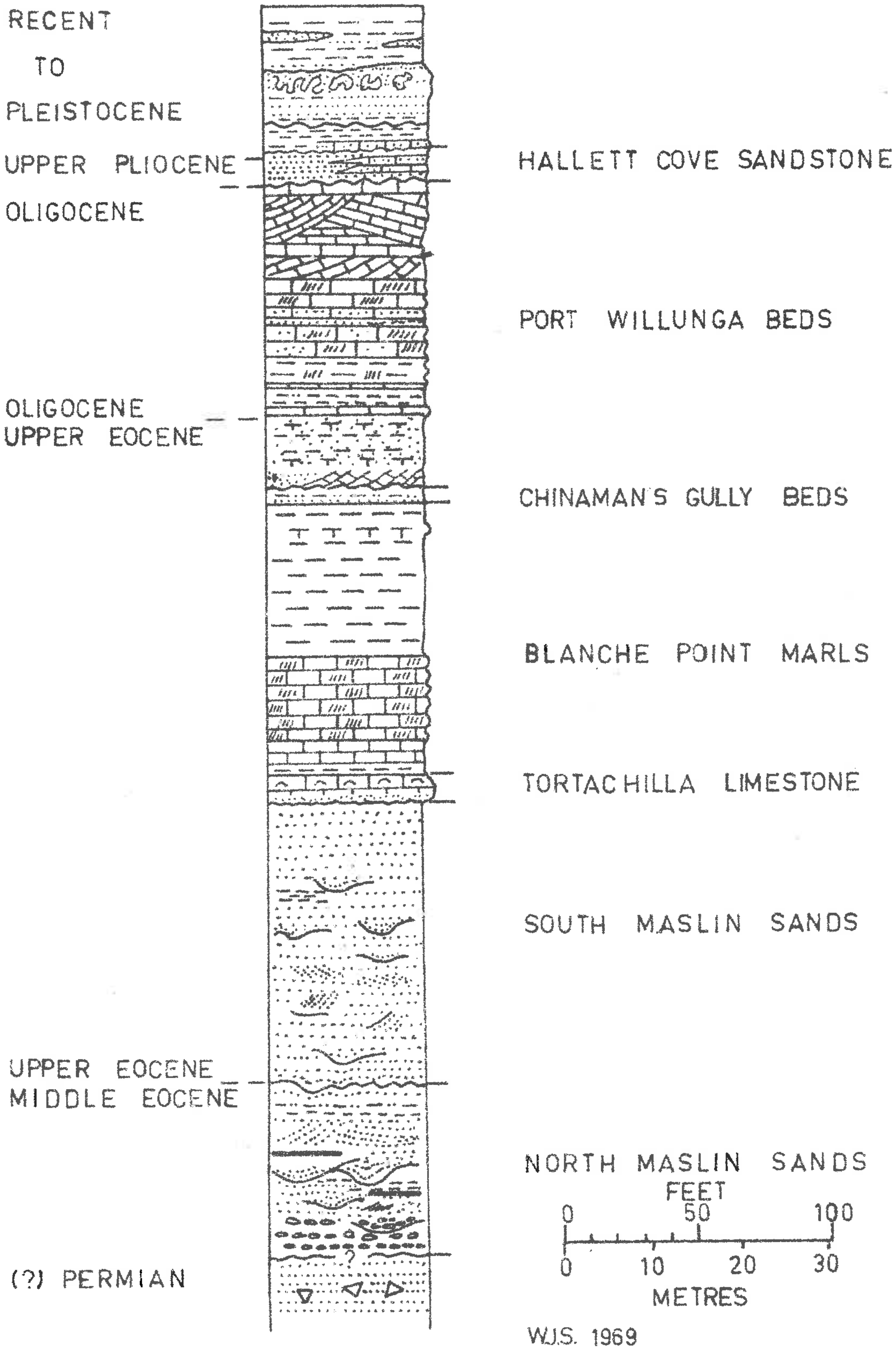
General Statement

The beginning of Tertiary deposition is documented by Middle Eocene fluviatile sediments unconformably overlying basement on the eastern and northern sides of the St. Vincent Basin. They often fill small erosional hollows in basement. The names North Maslin Sand and Clinton Coal Measures have been applied by Reynolds (1953) and Harris (1966), to the eastern and northern basal fluviatile sediments, respectively. They are very similar in lithofacies, with dominant sands and lignitic sediments, and are of approximately the same age. Consequently, they are discussed as a whole in the main text.

The ingression of an Upper Eocene sea is documented by marine sediments around the margins of the basin (Glaessner, 1953b). In deeper parts of the basin marine deposition extended from the lowermost Upper Eocene to the lowermost Middle Miocene inclusive. In the Willunga Embayment these marine sediments (Text Figs. 1 and 2) are the South Maslin Sands, Tortachilla Limestone, Blanche Point Marls and Port Willunga Beds

Text Fig. 1 Stratigraphic column of Cainozoic strata exposed in coastal cliffs adjacent Maslin and Aldinga Bays. Modified after Reynolds, 1953.

TEXT FIG. 1



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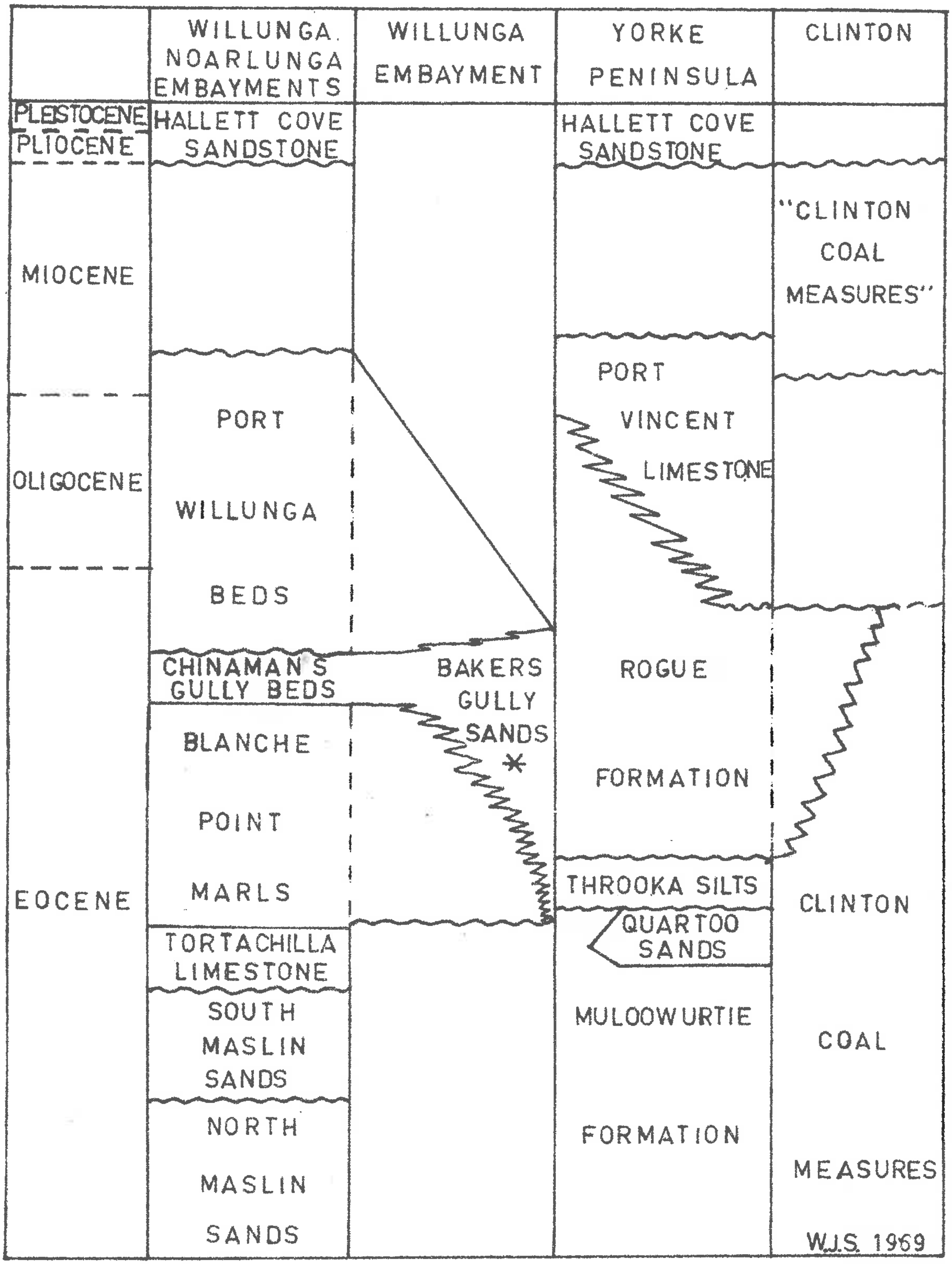
Text Fig. 2 Stratigraphic nomenclature chart of formations on the eastern, western and northern sides of the St. Vincent Basin.

TEXT FIG. 2



✳ GOLDEN GROVE SANDS - ADELAIDE EMBAYMENT

(Reynolds 1953). The Willunga, Noarlunga and Adelaide Embayments have similar sediments in surface sections and bores; Lower Miocene sediments in the Myponga Valley are reported by Glaessner and Wade (1958). On the east coast of Yorke Peninsula, Upper Eocene to upper Lower Miocene marine sediments in order of deposition (Text Fig. 2) are the Muloowurtie Formation (redefined), Rogue Formation (new name) and Port Vincent Limestone (new name). The Melton Limestone which is found at higher elevations in Yorke Peninsula (Glaessner, 1953b; Ludbrook, 1957b) is a marginal marine lithofacies of the Port Vincent Limestone.

In the Clinton area, Upper Eocene marine sediments (Johnson, 1960, 1964) are found in surface exposures and bores. Upper Eocene and Lower Miocene marine sediments are found in the subsurface of the Inkerman-Balaklava areas (Hillwood, 1961; Steel, 1961).

Along the eastern margin of the basin, complex facies relationships exist between marine and fluviatile sediments landward from the present Gulf. In coastal sections in the Willunga and Noarlunga Embayments, the Chinamans Gully Beds (Reynolds, 1953) are mainly lagoonal sediments. In the Willunga Embayment they are a lateral extension of the fluviatile Bakers Gully Sands (redefined) which are located inland from the coastal sequence. However, in the Noarlunga Embayment similar sediments have not been preserved inland. Fluviatile sediments of similar age to the Bakers Gully Sands are exposed in the Golden Grove area in the Adelaide Plains Embayment. Upland sands in the Barossa Valley (Dalgarno, 1961), and in the Meadows area, are of mid-Tertiary age (Harris and Olliver, 1965; Harris, pers. comm.). On the east coast of Yorke Peninsula, a lagoonal facies (Throoka Silts, new name) is found above the Muloowurtie Formation and below the Rogue Formation. These sediments were deposited slightly earlier than the lagoonal sediments in coastal sections of the eastern area (Chapter 3). Because facies relationships and sedimentary patterns are very complex and formational boundaries do not correspond to time lines, the descriptions and stratigraphic relationships of these formations are presented on an areal basis in the text (pp. 40to164).

Following pronounced tectonic movements between lower Middle Miocene and Lower Pliocene, the Upper Pliocene - Pleistocene marine sediments, named the Hallett Cove Sandstone (Crespin, 1954), were deposited on the eastern, western and southern margins of the basin. The name Dry Creek Sands has been applied by Glaessner (1951) to subsurface marine sands of Pliocene age in the Adelaide Embayment. These sediments are of approximately the same age and overlie unconformably older sediments and basement. They are discussed on pages 164 to 191.

Definition of Terms

Lithological Terms

The terms used here for clastic rocks are based on the standard grade scale of Wentworth (1922). Conglomerates usually vary from granules through the pebble grades; their composition is summarized in the text. Since most sandstones here contain a high quartz content, the sandstone classification of Grout (1932) is considered appropriate, i.e. quartz sands and sandstones. The adjective "arenaceous" is prefixed to other sedimentary rocks which contain an appreciable amount of sand-size quartz. The adjective "siliceous" implies an appreciable amount of silica cement in any sedimentary rock. The subordinate materials in a rock may vary between 10 and 50 percent. The grain size terms are shortened in the text by eliminating the use of the word "grained".

Both claystones and siltstones are defined by the predominant constituents according to Wentworth's classification. Although the name claystone does not imply any type of mineralogy, it is likely that grains less than 0.004 mm in diameter belong to the general group of clay minerals or hydro-micas. Clay minerals are not restricted in size and may range into the silt and sand grades. The adjectives "argillaceous" and "silty" imply an appreciable amount of clay and silt grade material, respectively. The adjective "glauconitic" also is used for an appreciable amount of mica-like clays with subordinate montmorillonite. Greenish glauconite here shows physical characteristics similar to those summarized by Burst (1958).

The term "limestone" is applied to those rocks in which the carbonate fraction exceeds the non-carbonate constituents. The carbonate classification of Sander (1967), which is a modification of Grabau's earlier classification, is easily applied to carbonate rocks in this area. Such terms as "calcilutite", "calcarenite" and "calcirudite" are used with names of common fossils as modifiers, e.g., bryozoal calcarenites. The adjective "biogenic" is used here for limestones that dominantly consist of relics of a variable fauna. The term "sparry calcite" cement implies filling up of available pore space in carbonate rocks where micrite (micro-crystalline ooze) has been washed out (Folk, 1959; 1962). The carbonate classification of Folk (1959) which is mainly based on the percentages of allochems, micrite and sparite often can not be used in this area because available pore space is not filled. Following the European usage of the term "marl" (or "marlstone"), several workers here have applied it to very fine-grained biogenic limestones or calcareous claystones. The dominant carbonate or noncarbonate constituent, and appropriate modifiers, are applied to these rocks in preference, because the term "marl" covers too wide a compositional range.

Small samples of disaggregated rock were quartered, and the degree of sorting, either in quartz sandstones or carbonate rocks, was generally considered from observations made under a binocular microscope. The overall distribution of grain size ranged from poorly- to well-sorted.

Stratification

The descriptive terminology of McKee and Weir

(1953) has been used to describe both cross-stratifications and bedding thicknesses. The adjective "resistant" is applied to rocks which weather more slowly than adjacent rocks.

Unconformities

The terminology of Dunbar and Rodgers (1957) is used for the description of angular unconformities and disconformities. The term "disconformity" is here applied to an erosional surface separating parallel beds. A temporal break (hiatus) may or may not be documented by the fauna or flora present in adjacent beds. If an erosional surface between beds indicates a small temporal break, the environmental interpretation of rocks becomes important. For example, a thin lagoonal deposit separates marine sediments of Upper Eocene age. Erosional surfaces either above or below the lagoonal sediments are considered local disconformities. If marine deposition continued elsewhere in a basin, these disconformities are actually very gentle angular unconformities. On the other hand diastems which also record small temporal breaks often are not recognizable (Barrell, 1917). Erosional surfaces below cross-stratifications and channels in a fluviatile environment, and local scour and fill surfaces in marine limestones, are occasional diastems that can be recognized.

Stratigraphic Relationships

The terminology of Krumbein and Sloss (1964) is used for designating offlap and overlap relationships in marine sediments. The context of the terms "overstep" and "onlap" in an overlapping succession shows which meaning is intended. The facies concept of Gressly (1838) and Teichert (1958) is well known; the lateral changes within a stratigraphic unit are facies changes.

North Maslin Sands - Clinton Coal Measures

Definition

The beginning of Tertiary deposition is documented by Middle to Upper Eocene fluviatile sediments unconformably overlying basement on the eastern, northern and northwestern sides of the St. Vincent Basin. They often partly fill small erosional hollows in basement. These sediments are fluviatile: channel, lateral, or point bar and flood plain deposits.

Reynolds (1953) applied the name North Maslin Sands to a sequence of quartz gravels, sands and silts which included thin clay beds. At that time lignitic sediments were not included in the definition of the North Maslin Sands because they were not exposed in their type section at Maslin Bay, Willunga Embayment. However, for many years bores had encountered lignitic sediments in time-equivalent sequences based on superposition. In 1967 a lignite was uncovered in the Noarlunga sand quarry at the type section and it is described on page 33. Lignitic sediments are here included within the North Maslin Sands. Glaessner (1953b) correlated the North Maslin Sands in the Willunga Embayment with Eocene fluviatile sediments in the Noarlunga and Adelaide Plains Embayments. These sediments are similar to those of the Clinton Coal Measures except the latter usually contain a greater percentage of lignitic sediments. The North Maslin sands are considered of Middle Eocene age at its type section while the lower part of the Clinton Coal Measures on the northern side of the basin are of Middle to Upper Eocene age (Harris, 1966). **Mid-Tertiary fluviatile sediments in** the Clinton area have been given the same name by Harris (1966) although they are separated by an unconformity within the formation. It is not within the scope of this thesis to clarify the stratigraphic nomenclature in this area as no subsurface material was available to me. At present available subsurface data between the Balaklava-Inkerman and Clinton areas (Map 1) and the Adelaide Plains Embayment to the south do not allow formal discussion of lateral continuity of these sediments, so both the names North Maslin Sands and Clinton Coal Measures are used here.

Distribution and Thickness

On available data the greatest definite thickness of the North Maslin Sands in the Adelaide Plains, Noarlunga and Willunga Embayments occurs adjacent to arcuate faults (Map 4). Slightly younger Upper Eocene, fluviatile sediments are exposed on the northeastern sides of the Adelaide and Willunga Embayments (p. 108). The Adelaide Plains Embayment contains the greatest known thickness of fluviatile sediments. In the Croydon bore, Glaessner and Wade (1958), following Tate (1898), estimated a thickness of 482 feet (147 m), whereas on physical grounds Steel (1962) considers that the basal 268 feet (81.3 m) of sediments are probably Permian glacials. These are tentatively considered Permian sediments here. Further, Steel places sediments between 1905 and 2030 feet (581 and 619 m) in the North Maslin Sands. Although Rao (1955) did not place the basal 268 feet (81.3 m) of sediments into the Permian, he considered the sediments between 1770 and 2242 feet (539 and 683 m) to be equivalent to the South and North Maslin Sands (undifferentiated). Palaeontological examination of samples below 1770 feet (539.8 m) shows contamination by foraminifera from younger Upper Eocene to Miocene beds above. The carbonaceous and micaceous sands and clays, a minimum of 272 feet (83 m), are physically similar to the fluviatile North Maslin Sands.

Towards the southwestern margin of the Adelaide Embayment, The Waite bore (Miles, 1952) encountered Tertiary sediments to a depth of 1047 feet (319.6 m).

In this bore, the basal 147 feet (45 m) of pyritic nodular clay, lignites and sands, are probably fluviatile North Maslin Sands. Although basement was not reached in this bore, these sediments are found at a stratigraphic level similar to those encountered in the Grange and Croydon bores.

Inland, about 100 feet (30 m) of North Maslin Sands were encountered in bores south of Happy Valley Reservoir, adjacent to the Clarendon-Moana Fault in the Noarlunga Embayment (Map 4). To the west between the townships of Noarlunga and Moana, these sediments are slightly thinner in the subsurface. The full Tertiary sequence has not been penetrated in deeper parts of the Willunga Embayment. Seismic evidence (Drayton, 1962) suggests a possible thickness of 1000 feet (305 m) of sediments in the deepest part of the embayment. The Willunga Bore No. 1 penetrated 688 feet (210 m) of Upper Eocene to Lower Miocene marine and lagoonal sediments and Pliocene to Recent fluviatile sediments (Cochrane, 1956; Woodard, 1952) which are time equivalents to sediments that overlie the North Maslin Sands in coastal sections. This suggests a possible thickness of 200 feet (61 m) of North Maslin Sands and/or probable Permian fluvio-glacial sediments.

These sediments can not be differentiated on seismic evidence.

On the northern sides of the Willunga and Noarlunga Embayments the North Maslin Sands partly thin to a depositional edge. Onlapping relationships can be seen along the coast where coarser grained sediments fill erosional hollows in basement of the Noarlunga and Christies sand quarries. In the Willunga Embayment near the top of the sequence, finer grained sediments thin to an erosional edge just south of Ochre Cove; in the Noarlunga Embayment they fill erosional pockets towards Halletts Cove. Inland surface and subsurface data indicate that later marine sediments overlap the North Maslin Sands onto basement on the northeastern sides of the Willunga and Noarlunga Embayments and near the Hope Valley Reservoir area in the Adelaide Embayment. The Croydon, Grange and Port Gawler (Mines Department Observation bore F) bores penetrated a similar thickness, 230 to 272 feet (70 to 83 m) of basal fluviatile sediments on the downthrown side of the Para Fault (Map 4). Between Port Gawler and the Township of Two Wells, Seedsman (1967) has shown by seismic evidence apparent thinning of the North Maslin Sands over possible buried structures. Younger marine sediments appear to overlap these sediments onto proposed basement. North-northeast of the Croydon bore and west of the Para Fault no bores penetrated to basement, although approximately 13 feet (4 m) of these fluviatile sediments may be present at the base of the Elizabeth bore. Through gravity data, Rowan (1967) has shown decreasing depth to basement adjacent to the Para Fault, to the north-northeast towards Gawler Township. It is noteworthy that similar gravity trends in the Willunga Embayment (Drayton, 1962) compared with subsurface data tend to substantiate increasing values of gravity with decrease in thickness of sedimentary cover, rather than differential magnetic densities in basement (see Map 3). Thinning of fluviatile sediments towards Gawler seems likely when compared with overall trends in other embayments.

Thinning of the North Maslin Sands is documented across two faults; the Para Fault in the Adelaide Embayment, and the Clarendon-Moana Fault on the southern margin of the Noarlunga Embayment. The North Maslin Sands thin from 272 to 50 feet (83 to 15 m) across the Para Fault from the Croydon bore to the Kent Town bore (Map 4). One mile (1.6 km) south of Moana Township, on the southwest margin of the Noarlunga Embayment, the South Maslin Sands which unconformably overlie the North

Maslin Sands, overlie basement in coastal cliffs (Map 5). This suggests thinning of the North Maslin Sands at depth. In the same embayment approximately 20 feet (6 m) of lignites and sands which are correlated by subsurface mapping and palaeontology to the North Maslin Sands, are preserved south of the Noarlunga Township near sea level on the upthrown side of the Clarendon-Moana Fault. North of Noarlunga Township stratigraphic relationships are similar to those now found south of Moana. The South Maslin Sands overlie basement approximately 50 feet (15 m) above sea level. Although the North Maslin Sands are present at deeper levels in the embayments, they are notably absent directly south of the major faults except for the areas mentioned (Map 4).

In the Clinton area, subsurface data (Johnson, 1960, 1964) indicate that Middle to Upper Eocene fluviatile sediments have a maximum thickness of 350 feet (107 m). They trend northeast-southwest parallel to the coast. Upper Eocene marine sediments overlap these sediments onto basement in southern areas.

In the Inkerman-Balaklava area (Hillwood, 1961) the Clinton Coal Measures show below sea level a thickness of approximately 200 feet (61 m) and increase to 300 feet (91 m) towards the St. Vincent Gulf. Upper Eocene marine sediments interbedded with fluviatile sediments overlie this sequence (Hillwood, 1961).

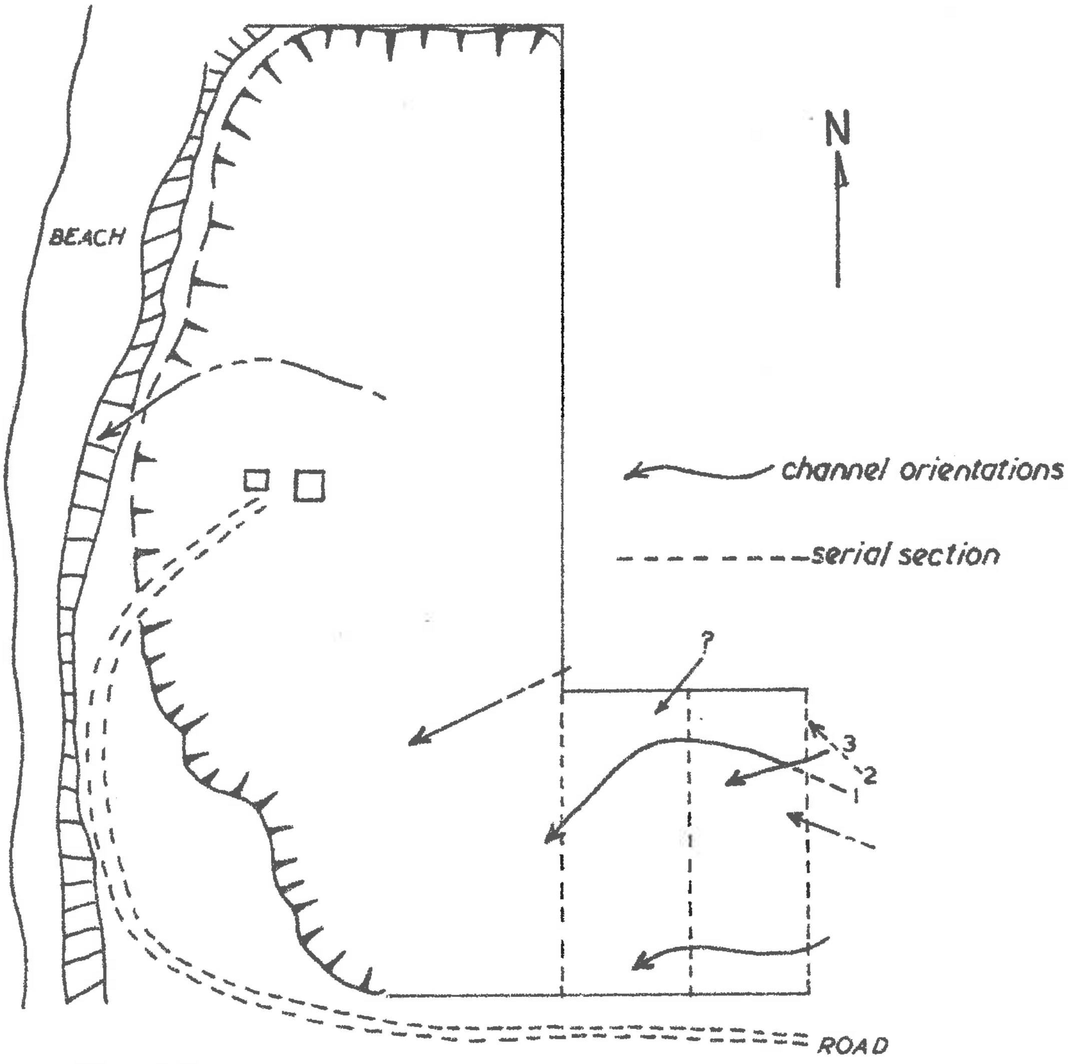
South of the Clinton area, inland in the vicinity of Ardrossan and Price Townships, quartz sands at higher elevations are correlated by Crawford (1965) with the Clinton Coal Measures. These sands are preserved in hollows of basement and vary in thickness with a maximum of 35 feet (11 m) at Correll's sand quarry. A small remnant of fluviatile conglomerate is present just south of section 9 (Chart 3A). Sands and gravels, 54 feet (16 m) thick, are found 485 feet (147 m) below sea level in the Black Point bore (Chart 4). South of Black Point on the eastern coast of Yorke Peninsula and at basal levels in the Troubridge bore, fluviatile sediments of Middle to Upper Eocene age are absent.

Lithology and Sedimentary Structures

In the Willunga and Noarlunga Embayments, surface exposures of North Maslin Sands consist of poorly-sorted, micaceous, fine to very coarse quartz sands with medium to large scale cross-strata (planar, tabular; trough, lenticular) in the basal parts (Pl. 1, Fig. 1). In the lower 30 feet (9.1 m) of the sequence in the Noarlunga sand quarry, channels are occasionally present. Both symmetrical and asymmetrical simple, U-shaped channels (Bluck and Kelling, 1963) are occasionally present. The width of these channels varies between 30 and 50 feet (9.1 and 15 m) and the height is approximately 15 feet (5 m). The basal erosional surfaces of the channels truncate adjacent strata below channel profiles. Pebbles 2 to 8 cm in length form channel-lag deposits in lower parts of the formation (Pl. 2, Fig. 1). They are replaced by coarse to very coarse sands in channels higher in the sequence. Grain size decreases from medium to fine sands both vertically and laterally in some channels whereas only vertical fining occurs in others. There is evidence of lateral thinning of strata towards the axes of later channels while thinning occurs on margins of earlier channels. This may indicate both lateral and vertical filling. Serial sections observed during excavation of the quarry show gentle, convex patterns of channels to the north (Text. Fig. 3). The northernmost channel contains angular quartzite pebbles at its base, derived from adjacent outcrops of basement quartzites. The same channel cuts down into probable Permian sediments of the west side of the quarry.

Text Fig. 3   Location of channels exposed in the Noarlunga sand quarry, Maslin Bay.

TEXT FIG 3



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Small scale, planar, tabular cross-strata are found on the concave sides of channels, dipping obliquely towards the channel axis. Internal bedding is similar viewed in sections at right angles. These sediments are similar to the lateral bars shown by J.R.L. Allen (1966).

In the upper part of the formation (30 to 35 feet; 9 to 11 m) in the Noarlunga sand quarry, numerous small channels, 10 x 5 feet (3 x 1.5 m), cross-strata (planar, tabular and wedge) and lenticular very fine sands, silts, clays and lignite are common. Numerous small scours are associated with the cross-strata. There is a general fining in grain size upwards from medium and coarse sands to very fine sands, silts and clays. Very fine sands show parallel laminae to very thin beds and asymmetrical ripple marks, whereas clays and silts show parallel or wavy laminae. These sediments are not restricted entirely to the upper parts of the formation. A few remnants of lenticular silts and clays have been preserved in lower parts of the formation where streams were actively downcutting (Pl. 1, Fig. 1). These sediments included with the channels show minor incomplete cycles fining upwards. The tendency within the whole of the sequence is fining of grain size towards the top of the formation. In Albert's sand quarry large scale, planar (wedge and tabular), cross-strata are the most common sedimentary structures at the present time (Pl. 2, Fig. 2). The cross-strata dip 20 to 30 degrees to the west (Brown, 1960). At right angles the cross-strata show parallel laminae and very thin beds 10 to 40 feet (3 to 12 m) long. A few lenticular clay beds are present. A possible small channel (15 x 7 feet; 4.6 x 2.1 m) orientated in a northwest-southeast direction was noted on the south face of this quarry stratigraphically lower than previously mentioned structures.

On the northern side of Noarlunga Embayment approximately 60 feet (18 m) of North Maslin Sands overfill an erosional hollow in the Christies sand quarry (Wade, 1952). The quarry (Map 4) was discontinued since Wade's work and filled in with dump material. She noted that the sediments were highly cross-stratified, coarse sands. These sands are capped by a 2 foot (61 cm) pre-Pliocene iron-stone. Just north of the quarry laminated clays, silts and sands with minor cross-strata still occur, and this sequence also fines upward. At Whitton Bluff, Glaessner (1953a, b) noted a buried lateritic soil profile near the top of the formation, and brackish water foraminifera which indicate proximity of a shoreline. Approximately 20 feet (6 m) of the formation exposed here is composed of laminated clays, silts and fine sands now variegated by lateritic weathering.

Published subsurface data (Miles, 1952; Mining Reviews, Department of Mines, S.A.) show inland sequences of lignites, lignitic clays and sands interbedded within the formation. In the Adelaide Embayment 222 feet (68 m) of North Maslin Sands sometimes show an overall fining-upward sequence; gravels and sands are overlain by sandy lignitic clays in the Grange bore, whereas in the Croydon bore fine and medium-grained sands are interbedded with sandy clays and silts, and no overall internal organization is recognized. Similar undifferentiated sediments are known from several bores in the proximity of ancient fault lines. Glaessner (1953b) has noted that "in several instances lignitic areas end abruptly against faults without reappearing as expected in the upthrown position of the same formation". Although this is not the case on the southern margin of the Noarlunga Embayment where lignitic sediments are found on the upthrown side of the Clarendon-Moana Fault (Daily, 1952, and Wright, 1961), the greater distribution of finer-grained sediments in depressed areas appears valid on available information.

Although lignites are seldom found at the surface one was exposed 20 to 25 feet (6 to 8 m) below the top of the North Maslin Sands in the Noarlunga sand quarry (Pl. 3, Fig. 1). The lignite is elliptical in plan view and lenticular in cross-section. The edges of the lignite minutely intertongue with white and yellowish grey fine to medium sands and its base is concordant with similar sands. Richly organic black clay with abundant leaf, seed and twig remains occurs near the middle of the lens. Pale brown clays found both towards the top and base of the lens contain leaf impressions which suggest oxidizing conditions (Pl. 3, Fig. 2). The lignite contains many parallel laminae often disturbed by vertical roots in part lined with organic material, pyrite and traces of marcasite. Pyrite concretions are common. Disseminated pyrite is found along a few bedding planes. These minerals are common in lignitic sediments found in the subsurface. Small channels with medium to coarse sands are situated adjacent to the lignite.

On the east coast of Yorke Peninsula Eocene fluviatile sediments are found in the B.H.P. and Crowell's quarries and in other areas to the north

(Crawford, 1965). In the quarries fine to granule sands contain small to medium scale cross-strata (planar, tabular and wedge; trough, lenticular). These sands are found at approximately 200 to 250 feet (61 to 76 m) above sea level. Small channels are present within the two quarries. Channel-lag deposits are common over an irregular basement surface which shows approximately 15 feet (5 m) relief in the B.H.P. quarry.

Palaeocurrent Analysis

Palaeocurrent analysis of cross-strata was attempted to establish the dominant directions of stream transport of Middle to Upper Eocene sands. It is apparent that only a few locations are suitable for direct measurement of current directions within the basin, so that conclusions can only be tentative.

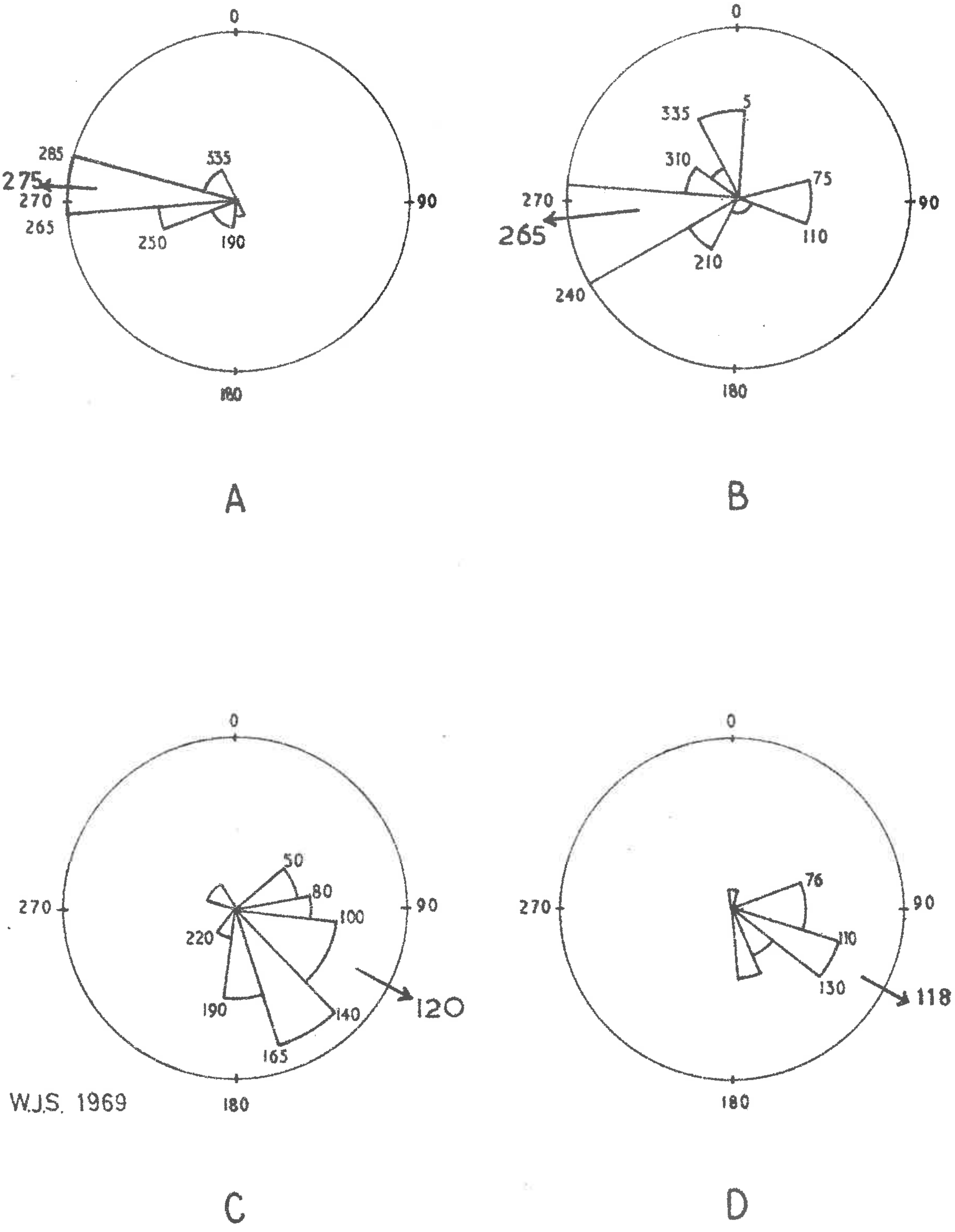
J.R.L. Allen (1965) and Williams (1966) have shown that planar cross-strata in point bar or channel bar deposits deviate in directional properties from the true direction of current flow. Stream channel orientations are given first preference in determining directional current systems whereas planar cross-strata are considered as second order or a component to the true direction of flow. In the Noarlunga sand quarry stream channels (Text Fig. 3) are essentially oriented in an east to west-southwest direction. Cross-strata show a wide variation but the mean is to the west (Text Fig. 4). In Albert's sand quarry planar, wedge cross-strata are oriented to the west (Brown, 1960). This, and the orientation of channels in the Noarlunga sand quarry suggest a westerly transport. Channel and cross-strata directions in the B.H.P. quarry and Crowell's sand quarry near Ardrossan on the east coast of Yorke Peninsula indicate transport to the east-southeast (Text Fig. 4). On available data Middle to Upper Eocene fluviatile sediments indicate transport towards the present axis of the St. Vincent Gulf.

Constituents

Micaceous sands within the formations are texturally immature to mature. Quartz comprises at least 95 percent of the sands. Mica is the most common accessory mineral with subordinate minerals tourmaline, zircon, leucoxene, rutile, garnet and opaques. Medium to coarse sands are subangular to subround, roundness: 0.4-0.6, with a sphericity factor of 0.5-0.7. A few grains of quartz, less than 5 percent, are highly rounded and spherical. In general sediments are poorly-

Text Fig. 4   Cross-strata directional properties measured from (A) Noarlunga sand quarry, (B) Albert's sand quarry, (C) Crowell's sand quarry, and (D) B.H.P. quarry. Arrows indicate mean direction of cross-strata. One radius equals 55 measured cross-strata.

TEXT FIG 4


0
90
180
270
285
275
265
335
250
190
A
0
90
180
270
5
335
310
75
110
265
210
240
B
0
90
180
270
50
80
100
220
190
140
165
120
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C
0
90
180
270
76
110
130
118
D

sorted near the base and moderately-sorted near the middle and top of the sequence where they decrease in grain size (Brown, 1960). Mature sands are commonly associated with lignites and clays in the subsurface. Immature sands, however, are common in small channels adjacent to the clays and lignite in the Noarlunga sand quarry. Sands in surface exposures at higher elevations on Yorke Peninsula are mature. Feldspathic grains are present in the basal 40 feet (12 m) of the Black Point bore. Arkosic sandstone fragments are found slightly higher in the bore.

Pebbles are essentially resistant rock types: white, grey and brown quartz, quartzite and vein quartz. White alunite and kaolinite pebbles are common at Noarlunga sand quarry. The mineralogy of pebbles exposed at the base of the sequence on Yorke Peninsula is similar except that arkosic sandstone and occasional limestone pebbles are common, presumably derived from local Cambrian sediments. Horwitz (1965) has indicated that laterite fragments are common in the lower beds of the Clinton Coal Measures.

The clay mineralogy of several samples from lenticular clays and argillaceous sands was examined. The most abundant mineral was kaolinite with traces of montmorillonite. Kaolinite with traces of montmorillonite, illite and jarosite was found near the top of the sequence associated with the laterite profile at Whitton Bluff in the Noarlunga Embayment (Analysis supplied by Dr. Hutton, C.S.I.R.O. Soils Division, to Glaessner, Stevens and Wade, unpubl. paper presented to A.N.Z.A.A.S., 1958). Lignitic sands and clays contain accessory minerals of pyrite, marcasite (trace) and gypsum (trace).

Depositional Environments

On the northern margin of the Willunga Embayment, numerous stream channels in the lower part of the sequence represent sinuous streams. These streams were rapidly downcutting and scouring as shown by the scanty preservation of floodplain deposits and superimposed channels. The streams were continually reworking previously deposited sediments by lateral migration and downcutting. Most streams show vertical filling. Channel-lag deposits consisting of pebbles and boulders are not present on the northern margin of the Noarlunga Embayment where medium to coarse quartz sands form the main channel-lag deposit. This area represents lower flow regimes when compared with the Willunga Embayment.

Smaller structures and finer grain sizes indicate decrease in stream competence upwards in the sequence. Channel-lag deposits probably occur in the Grange bore, Adelaide Plains Embayment. However only a few bores have penetrated these deposits. Lenticular very fine sands, silts, clays and lignites indicate deposition within ponds and swamps. Alternating reducing and oxidizing conditions are shown by empty leaf impressions at the base and top of the lignite in the Noarlunga sand quarry. Floodbasin deposits and swamps are more common in depressed areas adjacent to the Clarendon - Moana Fault in the Noarlunga Embayment.

The occurrence of resistant minerals (zircon, rutile and tourmaline), pebbles (quartz and quartzites) and predominant kaolinitic clay indicate highly weathered source rocks in the surrounding hills. Within the mineral suite, rounded zircons, tourmaline and rutile may indicate reworking of sedimentary rocks, whereas biotite, muscovite and leucoxene indicate a low-grade metamorphic source (Pettijohn, 1957). It is noteworthy that high grade minerals found in slightly younger, Upper Eocene, sediments are rare to absent in the North Maslin Sands. This important point shows that streams had not yet cut into high grade metamorphic rocks in the Mt. Lofty Ranges.

Eastern Area

In the eastern area marine deposition is indicated by basal glauconitic sands, South Maslin Sands, followed by carbonate and clay-rich sediments. The basal sands are fairly widespread in the Adelaide and Noarlunga Embayments and form thin (max. 20 feet, 6 m) sheet deposits. In the Willunga Embayment the sands are more than 100 feet (30 m) thick and form an estuarine complex. Inland in the Willunga Embayment similar glauconitic sands contain a marine micro-fauna equivalent to that of carbonate sediments stratigraphically higher than the sands in the coastal sections. This suggests the diachronic occurrence of the glauconitic sands. Similar relationships are found in the subsurface in the Adelaide Embayment. Tracing of strata and facies relationships generally clarify the overall stratigraphic relationships in places where structural complications and paucity of biostratigraphic control tend to complicate the setting. The Tortachilla Limestone, a thin (6.0 to 12 feet, 1.8 to 3.6 m) shelly formation, (Glaessner, 1953b; Reynolds, 1953) is only found in the Noarlunga and Willunga Embayments whereas approximately 40 feet (12 m) of arenaceous biogenic calcarenites, occurring at a stratigraphic level equivalent to the

Tortachilla Limestone are found in the Adelaide Plains Embayment. The next formation, the Blanche Point Marls (90 to 275 feet; 28 to 84 m) is widespread. In marginal areas inland of the Adelaide and Willunga Embayments the Blanche Point Marls in part are replaced by lagoonal, swamp and fluviatile sediments. Lagoonal deposition extended basinward during the Upper Eocene and the lagoonal Chinamans Gully beds accumulated above the Blanche Point Marls in marginal areas while marine deposition continued elsewhere. The marine Port Willunga beds overlie the Chinamans Gully beds. They indicate that marine deposition was once again fairly widespread in the eastern area.

South Maslin Sands

Definition and Distribution

The South Maslin Sands are exposed in coastal cliffs at Maslin Bay (Reynolds, 1953) near the northern margin of the Willunga Embayment, at Whitton Bluff (Wade, 1952) and one mile (1.6 km) south of Moana Township (Daily, 1952; Wright, 1961). Several exposures are found inland in the Noarlunga Embayment (Daily, 1952). Subsurface equivalents in the Adelaide Embayment have been noted by Ludbrook (1963a).

Basal Contact

The basal contact where the South Maslin Sands overlie the fluviatile North Maslin Sands is exposed in coastal cliffs, Noarlunga and Albert's sand quarries (Reynolds, 1953; Brown, 1960) and in a small quarry due east of the latter quarry. Reynolds (1953) shows a transitional contact between the formations whereas Glaessner (1953b) stated that the contact is an angular unconformity. Brown (1960) shows an erosional disconformable contact. At Noarlunga sand quarry, thin lenses of South Maslin Sand were reported 88 feet (27 m) above sea level on the eastern face of the quarry (Reynolds, 1953). Continued excavation in the quarry has revealed glauconitic sands at similar levels both on the southern and eastern faces of the quarry (Pl. 4, Fig. 1). Reynolds (1953) calculated the dip 7½ degrees in the direction 201° on the erosional surface and approximately, 1,000 feet (305 m) to the southeast where the dip flattens to 2°. At both localities the sands are gently dipping to the southwest.

In the Albert's sand quarry the base of the South Maslin Sands in the southwest part of the quarry is approximately 30 feet (9 m) below the base in the east and north parts of the quarry. Although Brown

(1960) shows basal sands of the South Maslin Sands thinning to the east, the fact that the South Maslin Sands overlap the North Maslin Sands from the southwest in Albert's sand quarry has been previously mentioned. Marine sediments gently overlap fluviatile sediments of coarser grain size and then progressively finer-grained sediments, towards the top of the North Maslin Sands in both a north and east direction. Where the erosional surface becomes vertical slight increase in dips of 3 to 5° occur in marine sediments. The South Maslin Sands were deposited over an irregular surface with a known relief of about 30 feet (9 m).

In the Noarlunga Embayment at Whitton Bluff the South Maslin Sands unconformably overlie the North Maslin Sands (Wade, 1952). The contact appears to be disconformable. No exposures to the north or inland show erosional surfaces similar to those irregularities found in quarries in the Willunga Embayment. In fact, glauconitic sands which underlie the Tortachilla Limestone extend 10 to 12 miles (16 to 19 km) inland east of Happy Valley Reservoir. One mile (1.6 km) south of Moana Township these sands unconformably overlie basement, and near Noarlunga Township overlie a thin sequence of lignites, clays and fine sands. In the subsurface they appear to overlie the fluviatile North Maslin Sands.

Thickness

In the Willunga Embayment the South Maslin Sands show a thickness of 135 feet (41 m) in coastal cliffs at the type area. Thinning of these sediments to the north and east in the Noarlunga and Albert's sand quarries is caused by overlap and erosion. On the southern margin of the embayment approximately 1½ miles (2.4 km) south of Sellick Beach Lower Miocene limestones overlie basement and older sediments wedge out at depth (Glaessner, 1953b). Inland the sediments show lateral facies variations, e.g. in the Willunga Bore No. 1 the full sequence was sand. From subsurface data these marine sediments and possible fluviatile equivalents wedge out on the eastern and northeastern margins of the embayment (Chart 5). In the Noarlunga Embayment the formation maintains a fairly uniform thickness of 10 to 15 feet (3.0 to 4.5 m). The formation overlaps the North Maslin Sands onto basement one mile (1.6 km) south of Moana Township (Map 5). Similarly in the Adelaide Plains Embayment the sands thin from approximately 30 to 40 feet (9 to 12 m) in the Grange and Croydon bores on the north side of the Para Fault to less than 15 feet (4.5 m) in bores on the southeastern side of the fault. No sediments of this age are exposed on the margins of the embayment.

Internal Features

In coastal cliffs at Maslin Bay the South Maslin Sands were defined by Reynolds (1953). They are sparingly fossiliferous, glauconitic and goethitic, fine to medium, quartz sands with small to large scale cross-strata, planar, tabular; trough lenticular (Brown, 1960). Pebbles inter-mixed in a sand matrix are common at the base of many cross-stratified sets. Numerous channels are found within the sequence and are similar to those described by Dott (1966, Fig. 15). Each channel shows a discordant erosional surface to underlying sediments, becoming pseudo-concordant towards the margins (Pl. 4, Fig. 2). However, most margins are truncated by superposed channel sediments or thin-bedded sands. Commonly thin layers of pebbles and clay galls are found at base. However, these are also found at various levels within the channel aligned parallel with bedding. Clay galls are also present in cross-strata (Brown, 1960) which are unrelated to specific channels. Numerous iron concretions are found at random throughout the type section except in the upper 20 feet (6 m). Thin bands of iron-oxides are concentrated along bedding planes in a few cross-stratified sets. Numerous worm burrows cut through laminae in cross-stratified and parallel laminated sands (Brown, 1960). At the top of the formation a thin-bedded, mottled layer indicates bioturbation. Brown (1960) indicated that well sorted, clean medium quartz sands unconformably overlying the North Maslin Sands on the south face of Albert's quarry, suggest reworking of the North Maslin Sands. They in turn are unconformably overlain by glauconitic, fine to coarse sands with parallel thin to thick bedding and rare small scale cross-strata (trough, lenticular). In a small quarry just east of Albert's quarry approximately 10 feet (3 m) of glauconitic sands with parallel thin to thick bedding and numerous burrows are exposed in the east face.

Although inland exposures are poor in the Willunga Embayment, Glaessner, 1953b (in Cochrane, 1956) indicated that the Willunga Bore No. 1 penetrated 62 feet (19 m) with carbonaceous quartz sands at base without reaching basement. The sands are sparingly fossiliferous (Ludbrook, 1956), and underlie slightly younger marine sediments equivalent to the basal part of the Blanche Point Marls in the coastal sequence (Glaessner, 1953b). Medium sands with granules, glauconitic and siliceous sponge spicules become increasing carbonaceous, argillaceous and silty towards the base of the bore (Chart 5). These sands are considered by Glaessner (1956) to be either equivalent to the North Maslin Sands, South Maslin Sands or the Tortachilla Limestone with preference to the North Maslin Sands. Ludbrook (1956) thought that Glaessner's latter suggestion (Tortachilla limestone) was more significant since marine fossils are found within the sands. Reynolds (1953) and Brown (1960) show clearly that the South Maslin Sands contain glauconitic casts of fossils which Ludbrook (1963a) considers to be typical of an 'estuarine' environment. Casts of marine foraminifera have been found near the top of the formation. These sands are considered here facies equivalents of the South Maslin Sands and the Tortachilla Limestone.

In the Noarlunga Embayment at Whitton Bluff, the South Maslin Sands mainly consist of variegated green and maroon, glauconitic, fine to coarse sands (Wade, 1952). In contrast to the coastal formation in the Willunga Embayment where the sands are highly cross-stratified, laminated to thick parallel bedding is predominant here and at other exposures in the embayment. Laminae of pale yellow clay are common throughout the formation. Burrows within the sands are numerous but concentrations of iron-oxides are absent. At Whitton Bluff and in a road-cut 1 to 1.5 miles (1.6 to 2.4 km) to the east of Port Noarlunga, the top of the formation is extensively bioturbated. Callianassa burrows (Wade, 1952) are filled with poorly-sorted sand and granules from the Tortachilla Limestone above, and have been subsequently cemented by calcium carbonate (Pl. 5, Fig. 1). This part of the formation ranges in thickness from 1.2 to 2.5 feet (36 to 76 cm). Erosion and burrows that penetrate to different depths cause this variation in thickness (Pl. 5, Fig. 2). The burrows in part enclose irregular pockets of well-sorted, glauconitic medium sands, showing either "honeycomb" or brick-like structures. (Pebbles of South Maslin Sands are found unconformably overlying the formation.) Laminated brown clays, silts and very fine quartz sands interbedded with maroon-brown thin- to thick-bedded, medium to coarse sands are exposed in coastal cliffs one mile (1.6 km) south of Moana (Map 5). The mineral jarosite is fairly common here.

Laminated green-brown clays to fine sands grade vertically to cross-stratified green medium to coarse sands on the southeast bank on the Onkaparinga River near Noarlunga Township. Jarosite is less common than glauconite which gives the formation a green appearance. Heavy mineral concentrations and quartz form low dipping (8° to 12°), small-scale, trough cross-strata. Here, bioturbations are less common near the top of the sequence. Near the axis of the Noarlunga Embayment between Noarlunga and Moana glauconitic quartz sands change to mainly fossiliferous clays similar to those near the base of the South Maslin Sands south of Moana.

In the Adelaide Plains Embayment 30 to 40 feet (9 to 12 m) of marine glauconitic sands in the Croydon bore are found at a similar stratigraphic level to the South Maslin Sands. Patches of glauconitic sands with a fauna similar to that reported by Brown (1960) are noted by Ludbrook (1963a) in the subsurface in the North Adelaide and Kent Town areas, located immediately north and east from the city of Adelaide. The occurrence of casts of marine foraminifera near the top of the South Maslin Sands at Maslin Bay similar to those in the overlying Tortachilla Limestone and marine fossils from the South Maslin Sands in the Noarlunga

Embayment suggests correlation with marine sands containing a well preserved fauna near the base of the marine sequence in the Grange bore.

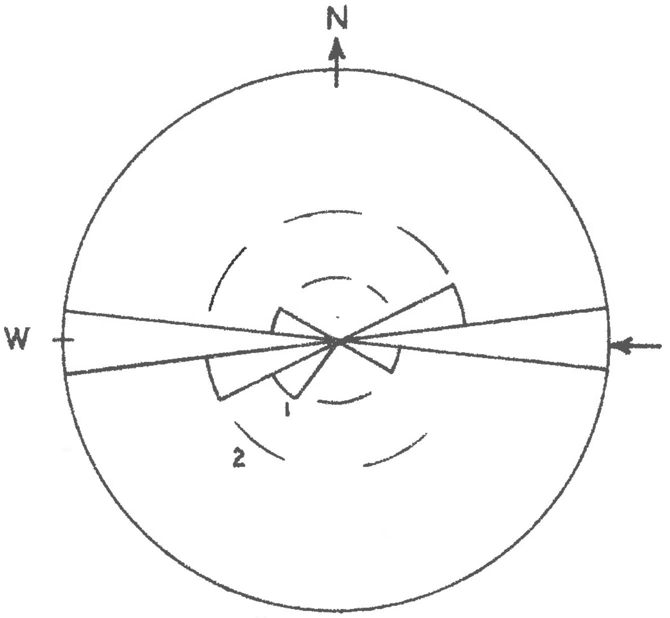
Palaeocurrent Analysis

Exposures of cross-stratified sands are limited to the coastal sections, quarries and the vicinity of Noarlunga Township. In coastal cliffs at the type area in the Willunga Embayment cross-strata show a polymodal distribution (Text Fig. 5). In two dimensional views, channel deposits and medium scale trough cross-strata are difficult to distinguish. Only three-dimensional views showing these sedimentary structures were taken into consideration where these difficulties arose. Four of the seven stream channels observed are oriented in an east to west direction (Text Fig. 5). Cross-strata data shown by Brown (1960) indicate a predominant mode to the south with a secondary distribution to the east and west. In part these are secondary cross-strata found on the margins of channels.

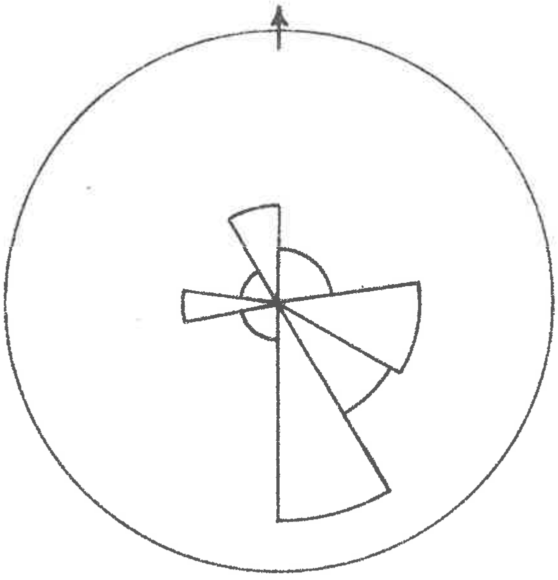
In Albert's sand quarry the sands occasionally show few cross-strata with parallel laminae and thin beds predominating. The sets that are present show a west direction with a secondary east trend. South of

Text Fig. 5 Channel directions (A) and cross-strata directional properties measured from the South Maslin Sands, Maslin Bay. Cross-strata data modified after Brown, 1960. One radius equals 55 measured cross-strata.

TEXT FIG 5



A.



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B.

the Onkaparinga River at Noarlunga Township low angle (8^{o} to 12^{o}), lenticular trough cross-strata show a northeast trend.

Constituents

Reynolds (1953) and Brown (1960) have presented lithological descriptions of the South Maslin Sands exposed in the Willunga Embayment. Overall the sands are variable in grain size from very fine to coarse with granules and pebbles very common. Medium sands are the most common, although rapid changes of grain size take place in alternating laminae. Quartz comprises between 80 and 85 % of the sands. Glauconitic and goethitic clays and lateritic fragments constitute 15 to 19 % of the sands with less than 0.5 % accessory minerals similar to those found in the North Maslin Sands. Internal moulds of foraminifera, faecal pellets, and clay encrusting quartz grains are present in the greater part of the clay fraction. It is noteworthy that variation in grain size of quartz grains, faecal pellets and pellets is similar in both fine and medium sizes indicating consistent sorting.

Subround to round quartzite and quartz pebbles are present especially at the base of large scale cross-strata and channels. Granules and small pebbles, 4 to 18 mm, are minor constituents. While pebbles are common in coastal cliffs in the Willunga Embayment they are less common in the Noarlunga Embayment.

In the Willunga bore glauconitic pellets and internal moulds of foraminifera increase from less than 1% at base to 2% near the top of the sequence. The glauconitic and some of the carbonaceous matter produces the drab green colour of the samples. Kaolinite with subordinate illite in clay forms 20 to 25 % of the samples near the base of the sequence.

Depositional Environments

The South Maslin Sands partly overlap basement on the northern side of a structural high that separates the Willunga and Noarlunga Embayments. Erosional thinning is inferred inland where younger, Upper Eocene, fluviatile sediments overlie basement in the north-eastern side of the Willunga Embayment (Chart 5). Numerous sand size to small pebbles of iron oxide are derived from laterites which were forming prior to and during the deposition of the North Maslin Sands (Glaessner, 1953b).

Describing the type area in the Willunga Embayment

Reynolds (1953) referred to the South Maslin Sands as the subaqueous part of a delta. Brown (1960) concluded from poor fauna and abnormal turbidity that the environment was estuarine.

An estuarine environment is further documented by east to west oriented channels in the formation. The magnitude of the channels suggests small streams although many of the margins are not preserved. Erosion of the channel margins by superposed channels show repeated lateral migration of distributaries. The continual reworking of thin clay layers within cross-sets explains the numerous clay galls. This may also account for the glauconite-rich character of the sediments. Burrows cutting through successive laminae in cross-sets indicate rapid deposition. In the upper part of the formation fossiliferous sands with bedding ranging from parallel laminae to thick beds, indicate marine sedimentation. These sediments are similar in the Albert's and Noarlunga sand quarries where they are overlying littoral sands. Marine erosion may have caused this relief by stripping of the South Maslin Sands, but channels found within the lower parts of the sequence may have initially modified the relief. Both erosional mechanisms were probably active.

Lignitic quartz sands containing a poor fauna in the Willunga bore indicate in part swamp and lagoonal sedimentation (Ludbrook, 1963a) towards the structural axis of the Willunga Embayment. Lithologies and fauna suggest marine influence towards the top of the sequence. East to northeast of the bore subsurface data indicate progressive swamp and fluviatile deposition.

In the coastal sequence channels oriented in an east to west direction and lithofacies inland indicate general flow of streams towards the present Gulf. The overall current direction determined by cross-strata is unimodal to the south which suggests either marine currents parallel to the ancient coastline (Brown, 1960) or preferred migration of channels. The deviations lower in the formation may be related to channel bars adjacent to estuary axes. Cross-strata associated with estuary axes shows a secondary east and west orientation. These may indicate interaction between tidal and drainage current systems (Emery and Stevenson, 1957). They conform to the general orientation of estuaries. Similar reversals in current directions are noted from the Rhine - Meuse estuary of the Netherlands (Oomekens and Terwindt, 1960).

In the Noarlunga Embayment the South Maslin

Sands are represented by a thin, shallow-water, sparingly fossiliferous, glauconitic, transgressive sand which covered most of the embayment. However, on its southern margin one mile (1.6 km) south of Moana Township and southwest of Noarlunga Township, the basal part of the sequence, which contains occasional fossils, jarositic clays, silts and very fine sands with parallel laminae to thin beds, indicates less turbid conditions; i.e. most likely a shallow water marine environment. South of Moana these sediments grade to massive, poorly-sorted sands whereas southwest of Noarlunga Township moderate-to well-sorted sands with low-angle cross-strata are found in the upper part of the sequence. Heavy mineral concentrations are found along bedding at the latter locality. The persistence of marine fauna upward in coarser-grained sand south of Moana indicates slightly shallower water with incomplete winnowing of fines, whereas southwest of Noarlunga a littoral or beach environment is envisaged. Small streams may have been delivering sediment from inland areas and/or marine denudation of the North Maslin Sands may have been the principal source of sediments.

Similar sediments to those found in the Noarlunga Embayment were being deposited in the Adelaide Embayment which shared the ingression of the Upper Eocene sea. They are poorly known from scattered bores. Thin estuarine sands near the city of Adelaide (Ludbrook, 1963a) indicate drainage areas from the surrounding hills. Marine sands overlying poorly fossiliferous carbonaceous and glauconitic sands in the Grange bore accord with a general transgressive sequence.

In summary, the deposition of the South Maslin Sands is very different in the Willunga, Noarlunga and Adelaide Embayments. Principal drainages are confined to the Willunga Embayment where approximately 135 feet (41 m) of estuarine and shallow water sands probably grade inland to swamp and fluviatile facies. Stripping and reworking of fluviatile North Maslin Sands occurred inland prior and probably during the deposition of the South Maslin Sands. In contrast, the formation in the Noarlunga Embayment and its equivalents in the Adelaide Embayment are very thin (max. 40 feet; 12 m), it extends further inland in the Noarlunga Embayment and in general represents basal transgressive marine sediments in both embayments. Large drainages are absent. In the Willunga Embayment surface exposures and subsurface data in northern areas indicate onlap relationships. Similar relationships are found on the southern margin of the

Noarlunga Embayment where shallow water to beach environments indicate a structural high which separates the two embayments. No sediments of this age are recorded on the southern margins of the Willunga and Adelaide Embayments. Marine sediments may have overlapped the present structural highs and been eroded prior to the deposition of Lower Miocene sediments but it is more likely that fault scarps adjacent to gradually subsiding areas provided barriers to marine transgression. The significance of structural movements is discussed in Chapter 5.

Tortachilla Limestone

Definition and Distribution

The formation is well exposed in coastal sections of the Willunga and Noarlunga Embayments (Reynolds, 1953; Wade, 1952). Inland several localities are reported by Daily (1952). Marine sediments that are equivalent in part to the Tortachilla Limestone are found in the Adelaide and Adelaide Plains Embayments.

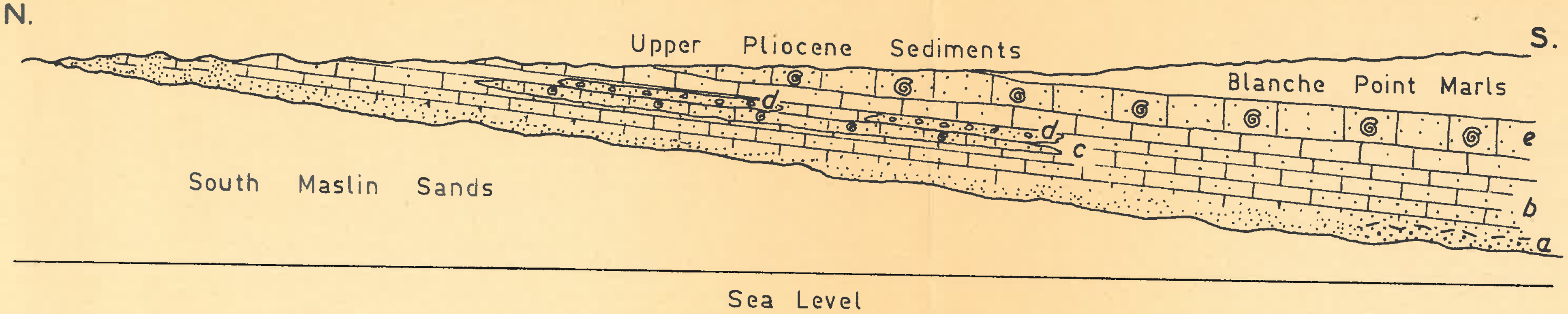
Basal contact

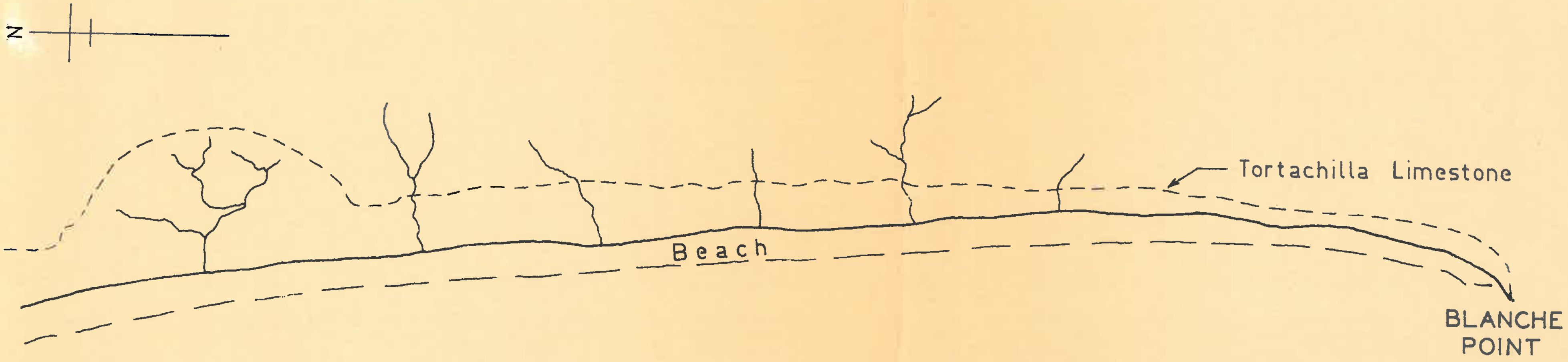
In the coastal cliffs at Maslin Bay, Willunga Embayment, Reynolds (1953) and Brown, (1960) considered that the Tortachilla Limestone unconformably overlies the South Maslin Sands. They place the contact at the base of bryozoal quartz sands which overlie poorly-sorted medium to granule sands with goethite. The surface seems to show small cut and fill structures (Pl. 6, Fig. 1; Text Fig. 6). However, on close inspection of the contact bedding laminae can be traced through this apparent cut and fill structure. While the bryozoal sands (b) contain calcareous fossils, the poorly-sorted sands (a) contain casts and internal moulds (Text Fig. 6). Leaching by fluids within the sediments has caused this apparent unconformity. The

Text Fig. 6 Cross-section and plan view of the Tortachilla Limestone exposed at Maslin Bay. For explanation of letters a-e see text.

DIAGRAMMATIC STRATIGRAPHIC SECTION OF THE TORTACHILLA LIMESTONE, MASLIN BAY

TEXT FIG. 6





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PLAN VIEW OF COAST (after Reynolds 1953) actual contact is found between 0.7 and 3.5 feet (21 and 106 cm) below the surface of leaching. The base of the Tortachilla Limestone is now placed where the poorly-sorted, leached sands infill burrows in the moderately-sorted sands of the South Maslin Sands (Pl. 6, Fig. 2). This contact forms an apparent disconformable surface. Approximately one mile (1.6 km) east of the coastal cliffs in a road-cut mentioned by Woodard (1952) similar relationships exist to those in the coastal sequence.

In the Noarlunga Embayment the Tortachilla Limestone unconformably overlies the South Maslin Sands at Whitton Bluff (Wade, 1952). Reworked, rounded ferruginous pebbles with infilled borings and boulders (Glaessner, 1953b) form a thin, 0.5 to 1.5 feet (15 to 45 cm) layer overlying extensively bioturbated South Maslin Sands. The surface is irregular and clearly an erosional surface (Pl. 5, Fig. 2). Unconformable surfaces are also recognized in the vicinity of Noarlunga Township (Daily, 1952) and just west of the Happy Valley Reservoir (Map 4). Seaward on a wave-cut platform one mile (1.6 km) south of Moana Township (Map 5) reworked pebbles of South Maslin Sand are found at the base of the Tortachilla Limestone (Wright, 1961). The erosional surface is similar to the coastal sequence at Whitton Bluff except that bioturbations are not found extensively in the top of the South Maslin Sands. The Tortachilla Limestone is not found in coastal cliffs adjacent to the wave-cut platform, 30 to 35 feet (9 to 11 m) above sea level, where light grey and yellowish grey sands (4) unconformably overlie the South Maslin Sands (2) (Map 5). The Tortachilla Limestone may partly grade to these sands (4) but is more likely to be absent because of overlap, the sands being the equivalents of the Transitional Marl Member (4a) of the Blanche Point Marls which overlie the Tortachilla Limestone on the wave-cut platform and at Maslin Bay. Similar relationships exist just north of Noarlunga Township where Wright (1961) noted the absence of Tortachilla Limestone.

Internal Features

In coastal cliffs at Maslin Bay near the northern side of the Willunga Embayment, the Tortachilla Limestone shows a maximum thickness of 12 feet (4 m). It extends from the north side of Blanche Point near sea level northwards in coastal cliffs, where Lower Miocene to Upper Pliocene erosion has limited it to a feather edge (Text Fig. 6). The formation contains variable sediments both laterally and vertically.

Dark, ochre-yellow, poorly sorted sands (a) at its base (0.7 to 3.5 feet; 21 to 106 cm thick) extend over the whole length of the outcrop. They grade vertically to light grey, arenaceous, bryozoal calcarenite (b) and to the south (Text Fig. 6), together they show a combined thickness of 7.2 feet (2.2 m). With the introduction of bryozoal shell fragments, the quartz and goethitic constituents decrease gradually, (inversely proportional with carbonate fragments) to approximately 30% in upper levels. Shell fragments and casts are often oriented parallel to bedding. As one proceeds northward from Blanche Point, a thin (1 foot; 30.3 cm) lens of arenaceous, biogenic, calcirudite (c) gradually alters to arenaceous, bryozoal calcarenites (Text Fig. 6). An abundant and variable fauna of brachiopods, echinoderms, corals, bryozoans, gastropods (Reynolds, 1953) are mainly oriented at random in micrite. Fine sand to granule size quartz and goethite constituents with scattered quartz pebbles (4 to 10 mm) form between 15 and 22% of the sediment. Within the arenaceous bryozoal calcarenites thin lenses of calcareous pebbly sands (d) with similar carbonate and noncarbonate constituents are also present. These sediments are found overlying the arenaceous calcirudites. Pebbles of brown quartz (4 to 10 mm) form approximately 5% of the sediment. Just north of this exposure in cliffs close to the coast, pale yellowish grey, moderately-sorted clean bryozoal calcarenites are found. An arenaceous calcirudite (e) with poorly indurated pockets of glauconite (Text Fig. 6) gradationally overlies this wide range of lithologies. It extends uniformly throughout the exposed sequence. The megafauna is similar to the fauna found in a lens in the lower sediments. It is listed by Reynolds (1953). The fauna is randomly oriented within micrite and the clay pockets contain few large fossils.

The glauconitic clay pockets enclosed by light grey dense carbonate give a mottled appearance to the exposure. Shell fragments, glauconitic faecal pellets and goethitic fragments in the light grey carbonate are common in micritic cement. This limestone is different from the lower arenaceous calcicrudite in that clay and micrite are more common.

In contrast to the Willunga Embayment, marginal exposures in the Noarlunga Embayment are thinner with a maximum thickness of 4.5 feet (1.4 m) and the lower bryozoa-rich sediments are absent. The formation is similar to the arenaceous biomicrudites in the Willunga Embayment. Pebbles of South Maslin Sands are more frequent at base in the Noarlunga Embayment whereas reworked sand size to granule fragments are common to both embayments. The Tortachilla Limestone is more widespread in outcrop and is found in the subsurface near the structural axis of the Noarlunga Embayment. In contrast in the Willunga Embayment outcrops are limited, and on bore data facies change to sands takes place inland (Chart 5). For these reasons a discussion of the Tortachilla Limestone in the Noarlunga embayment is warranted.

At Whitton Bluff resistant, arenaceous and glauconitic micritic calcicrudite is correlated by Wade (1952) with the Tortachilla Limestone at the type area. Ferruginous, burrowed pebbles derived from the South Maslin Sands are found at its base. The overlying arenaceous biomicrudite contains a similar megafauna with the addition of fossil crabs (Wade 1952). Internal features and constituents are similar to the arenaceous calcarenites in the type area.

Glauconitic clay (2 to 5%) encrusts carbonate and other constituents and gives the exposure a mottled appearance. Clay pockets are fewer compared with those in the Maslin Bay area.

Arenaceous, micritic, biogenic calcirudites are found inland 1.5 miles (2.4 km) east of Port Noarlunga in road cuttings, on the southwest bank of the Onkaparinga River in the vicinity of Noarlunga Township and immediately east of the Happy Valley Reservoir (Daily, 1952). At the latter locality weathering has produced a maroon and green mottling. Iron oxides and glauconitic moulds and casts are common.

One mile (1.6 km) south of Moana on the wave-cut platform sandy, coralline calcarenite is common. The formation (4.0 feet; 1.2 m thick) also contains reworked pebbles of South Maslin Sands at its base (Wright, 1961). Quartz and goethite grains are more common (35 to 45%). All constituents are within micrite.

Bores indicate an increase in thickness of the Tortachilla Limestone towards the axial part of the Noarlunga Embayment. The maximum known thickness of the Tortachilla Limestone here is about 12 feet (4 m). Micritic, biogenic, calcirudite is from an old bore located 3 miles (4.8 km) west of the Hackham Township whereas to the northeast in the vicinity of the new Marino Golf Course this formation is not recorded from several bores. In the Adelaide Plains Embayment the

Tortachilla lithofacies is not represented in available subsurface material. In the deep Grange bore basal sands are gradational to arenaceous biogenic calcarenites (Chart 6). Fossil shell fragments are more abundant than quartz sands and foraminifera in most of the sequence. Siliceous sponge spicules are also present, whereas goethitic constituents are not. The carbonate sequence in this position is approximately 40 feet (12 m) thick and near time-equivalent to the Tortachilla Limestone. In the Croydon bore light grey, moderately-sorted, fossiliferous, quartz sands, approximately 40 feet (12 m) thick, were found in a position equivalent to the carbonate sequence in the Grange bore. Similar sediments may be present near the base of the Elizabeth bore northeast of the Grange bore. At Port Gawler the Department of Mines Observation bore F contains sediments of a similar thickness (Seedsman, 1967). Sediments of this age were not penetrated in the Hallions bore west of Two Wells Township (Chart 6).

Near the southwest part of the Adelaide Embayment, the Taite bore shows general lithologies similar to deep bores in the Adelaide Plains Embayment (Chart 7). In North Adelaide on the northern margin of the embayment, glauconitic fossiliferous sands, 10 feet (3 m) thick, are of a similar age to the Tortachilla Limestone (Ludbrook, 1963a). However part of these sediments may be equivalent to the basal part of the Blanche Point Marls. From subsurface data (Miles, 1952) the marine Tortachilla equivalents are either thin or absent in marginal areas northeast and east of the city. Fossiliferous lignitic quartz sands underlying the Blanche Point Marls in several bores may in part be time-equivalent to the marine sediments in deeper parts of the embayments. From available data a pattern begins to emerge in the Adelaide Embayment. If the Taite bore located near the structural axis of the embayment is considered to show similar time and rock relationships to those found in the Grange bore in the Adelaide Plains Embayment, basal marine sands below Tortachilla Limestone equivalents transgress in time through the Tortachilla time interval to a position just below the Blanche Point Marls, or possibly in the lower few feet of that formation.

Blanche Point Marls

Definition and Distribution

The name Blanche Point Marls was applied by Reynolds (1953) to a sequence of marine marls, siliceous limestones and calcareous organic clays often containing sponge spicules, found in coastal cliffs in the Willunga Embayment (Text Figs. 1 and 2). The formation is approximately 100 feet (30 m) thick and gradationally overlies the Tortachilla Limestone. Reynolds recognized a threefold division of the formation into the Transitional Marl, Banded Marl and Soft Marl Members. The Transitional Marl, 7.5 feet (2.3 m) thick, contains olive-green, calcareous clays at base grading to light grey, glauconitic, foraminiferal limestone which constitutes the greater part of the member. This member is overlain by 37 feet (11.2 m) of siliceous sediments which form the Banded Marl Member. Hard layers, containing greater percentages of silica than soft layers, are accentuated by weathering (Pl. 7, Fig. 1). Silicified foraminiferal limestones with varying amounts of argillaceous matrix are predominant in this member. Approximately 60 feet (18 m) of light and dark brownish grey calcareous and carbonaceous clays, the Soft Marl Member, overlies the Banded Marl

Member. The Blanche Point Marls are overlain abruptly by the Chinamans Gully Beds.

Near the structural axis of the Willunga Embayment approximately 200 feet (61 m) of sediments penetrated in the Willunga Bore No.1 show little resemblance to the time-equivalent Blanche Point Marls at the coast (Glaessner 1953b). The Transitional Marls are replaced by yellowish grey and dark green marine sands in this bore (Chart 5). However, in this embayment the Transitional Marls show a distribution similar to the Banded Marls (Chart 5). Near the northern side of the embayment, two miles (3.2 km) north of McLaren Vale Township glauconitic sands (Chart 5) time-equivalent to the Transitional Marls, have overlapped older Tertiary formations onto basement in the H.B. 420 bore (Glaessner, 1953b).

The Banded Marl member, so easily recognizable in the coastal cliffs, is replaced by marine, calcareous silts and clays in the Willunga bore. Silicified fragments of limestone are very rare but have been observed near the top of these sediments. East of the Willunga bore, in bore 429 drilled on E. Rolands property (Cochrane, 1956) dark fossiliferous sands and clays occur at a stratigraphic level similar to the Banded

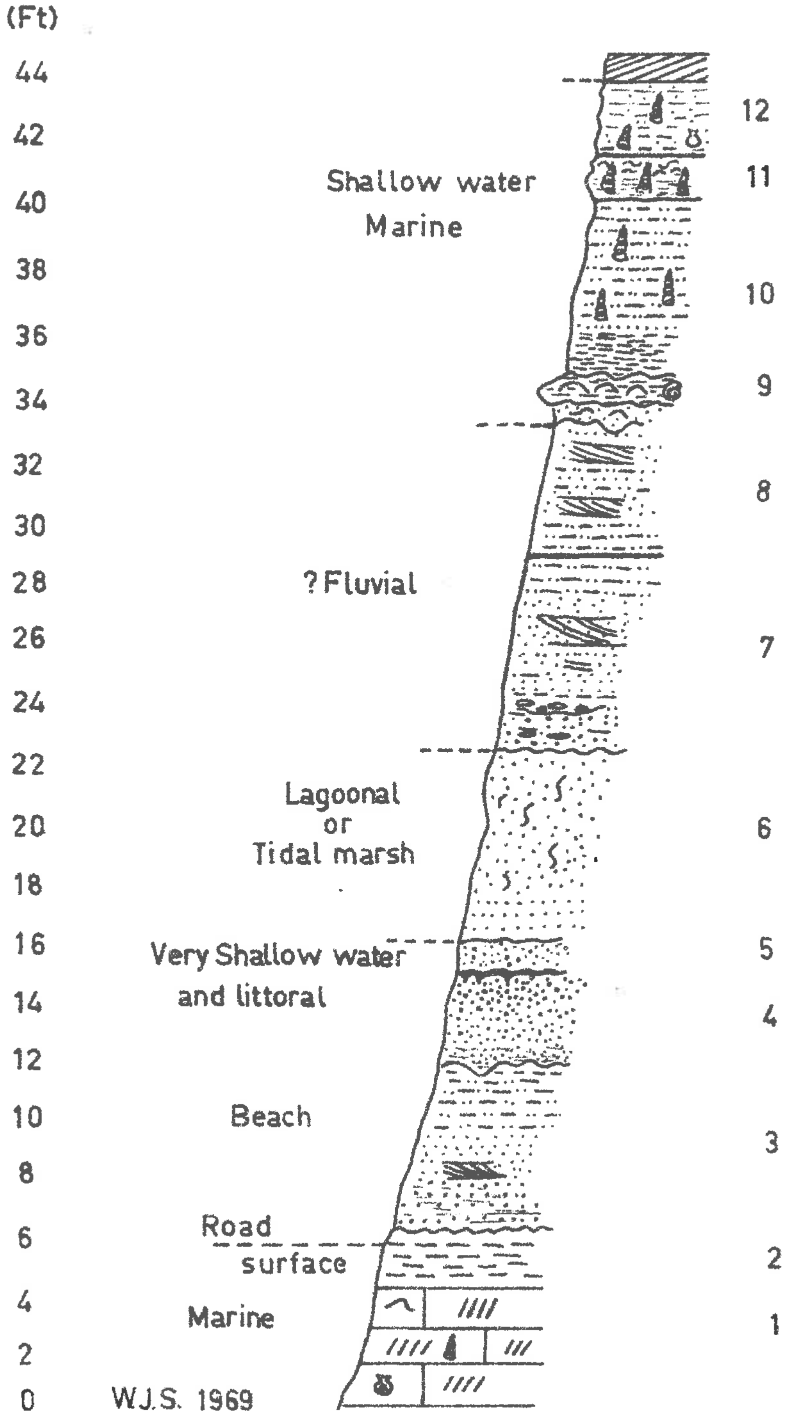
Marl equivalents in the Willunga bore (Map 6). Variations in facies in the embayment are shown in Map 6. From surface and subsurface data, the distribution of lithofacies extends inland from the coastal sequence to the vicinity of McLaren Flat. The limestones rapidly change to sparingly fossiliferous light grey sands in the northern and eastern sides of the Embayment.

Organic calcareous clays which form the Soft Marl Member in coastal sequences are replaced by marine organic, argillaceous silts grading upward to poorly fossiliferous sands in the Willunga bore (Chart 5). According to additional bore records and surface exposures, marine silts progressively change to sparsely fossiliferous sands and lignite from the top to the base of the member east and north of the Willunga bore (Chart 5). These sediments represent shoreline or transitional sediments between marine and fluviatile environments and clearly show offlap relationships. Interbedding of marine and nonmarine sediments is clearly seen 1 mile (1.6 km) north of McLaren Vale in a road-cut (Text Fig. 7). It is apparent in Text figure 7 that interbedded glauconite sediments on superposition are not related to the Tortachilla Limestone as has been

Text Fig. 7 Stratigraphic section of the Blanche Point Soft Marl equivalents exposed 1 mile (1.6 km) north of McLaren Vale, Willunga Embayment.

1. Silicified limestone, pale grey, glauconitic, fossiliferous.
2. Clay, dark olive green, silty, glauconitic, fossiliferous; contains limonitic stringers near base.
3. Sandstone and siltstone, pale yellowish grey and buff, very fine grained, argillaceous; contains limonitic stringers, laminated and occasional ripples.
4. Sandstones, grey white and pale greenish grey, medium grained at base and coarse grained at top, limonitic pellets, bioturbated.
5. Sandstone, dark olive green, fine to medium grained, argillaceous, glauconitic, very fossiliferous.
6. Sandstone, pale yellowish grey, very fine to fine grained, calcified root structures (Woodard, 1952).
7. Sandstone, pale grey to yellowish grey, medium to very coarse grained, planar cross-strata; contains lenses of quartz pebbles.
8. Sandstone and siltstone, pale grey, very fine to fine grained, very thin bedded; contains bands with limonitic iron staining.
9. Ferruginous Sandstone, grey and buff, fine to medium grained, silty, very fossiliferous; forms ledge.
10. Siltstone, grey to yellowish grey, arenaceous, argillaceous, slightly glauconitic, very fossiliferous.
11. Ferruginous Sandstone, same as unit 9.
12. Siltstone, pale greenish grey, arenaceous, argillaceous, micaceous, glauconitic, very fossiliferous.

TEXT FIG. 7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2
0
Shallow water
Marine
?Fluvial
Lagoonal
or
Tidal marsh
Very Shallow water
and littoral
Beach
Road
surface
Marine
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12
11
10
9
8
7
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4
3
2
1

indicated by Woodard (1952) and Sprigg and Wilson (1954, see Echunga Sheet). These sediments are interbedded in basal Soft Marl equivalents. Many diastems are represented within shoreline sediments. In the H.B. 420, McGeorge, and Whitstone bores these paralic sediments are replaced by fluviatile sands and swamp sediments (Chart 5).

In the Noarlunga Embayment from the north side of Whitton Bluff to Noarlunga Township, the three-fold division of the Blanche Point Marls has been documented by other workers (Wade, 1952; Daily, 1952). The thickness of this sediment is similar to that in coastal areas in the Willunga Embayment.

One mile (1.6 km) south of Moana Township the Transitional Marls are replaced by interbedded, variegated, sands, silts and clays which unconformably overlie the South Maslin Sands (Map 5). On the adjacent wave-cut platform the probable Transitional Marl consists of thin arenaceous glauconitic limestones (4a). These sediments thin to a feather edge both by erosion and onlap. They are similar to those exposed on the south side of the Onkaparinga River near Noarlunga Township. Numerous thin green bands of clay interbedded with siliceous sediments are common near Hackham Township. The Banded Marl Member can be traced to just east of Happy Valley Reservoir where it grades to shoreline calcareous quartz sands and pebble beds (Map 6). The basal part of the Banded Marl or the Transitional Marl Member becomes increasingly carbonaceous south of Happy Valley Reservoir (Olliver, 1967a) whereas the Soft Marl Member is restricted to the axis of the embayment. In northern and southern localities it thins to an erosional edge.

In the Adelaide Plains Embayment the three-fold division is partly recognizable in the Grange bore (Chart 6). The Transitional Marl and Banded Marl Member are present, but on physical grounds the Soft Marl Member cannot be differentiated from marine sediments of an equivalent age to the basal parts of the Port Willunga Beds, which overlie the thin paralic Chinamans Gully Beds at its type area.

The Transitional and Banded Marl Members are represented by marine, pale to dark grey sands and silts in the Croydon bore (Map 6). The silts are in part silicified within this interval. Greyish brown sands which grade to interbedded hard sand and silts near the base of the Elizabeth bore (see Mining Review 108, 1959) may be equivalents to these members from their similar position and similar trends in the Willunga Embayment. Calcarenites recognised in Hallions Bore, west of the Two Wells Township, are approximate time-equivalents (p. 198) to the Banded Marl Member in the Grange bore (Chart 6).

Near the structural axis of the Adelaide Embayment "white clays" recorded in the Taite bore (bore 214 in Miles, 1952) are found at a stratigraphic level similar to the Banded and Transitional Marls penetrated by the Grange and Croydon bores. This correlation seems probable when comparing thickness and sediments of the Taite bore to those of the Grange or Croydon bores (Charts 6 and 7).

On the northern margin of the Embayment subsurface data (see Miles, 1952) and surface exposures in building foundations, e.g. in the Adelaide Children's Hospital Foundation indicate the presence of the Banded Marl Member. Patches of glauconitic sands at the base of these sediments may be diachronic (p. 65). The Banded Marls extend northeastwards from the city of Adelaide to just south of Hope Valley Reservoir where they overlap older Tertiary sediments onto basement. Marine sands with a few interbedded lignitic sediments are found adjacent to the Blanche Point Marls north of the city of Adelaide and south east of Hope Valley Reservoir. The sands (Map 6) probably extend southeast from the city of Adelaide to Black Forest (bore No. 54 in Miles, 1952; and Howchin, 1935).

In the Adelaide Plains Embayment, the lower Port Willunga Beds and upper Blanche Point Marl time-equivalents consist of dark and light grey organic calcareous clays as seen in the Grange bore (Chart 6). Silty clays, silts and thin sands occur in the Croydon bore. To the north-east, in the Elizabeth bore, the sequence probably is replaced by dark grey and dark brownish grey fossiliferous silty sands interbedded with fossiliferous silty clays. Near the Township of Two Wells, the Hallions bore (Chart 6) penetrated pale to dark grey, glauconitic and calcareous silty clays containing sponge spicules. These sediments are interbedded with poorly fossiliferous, dark grey to black, lignitic, silty and arenaceous clays in lower parts of the sequence.

In the Inkerman-Balaklava area (Chart 6) very slightly fossiliferous dark grey, glauconitic and carbonaceous sandy clays and sands, interbedded with thin lignites, are correlated by Steel (1961) with the Blanche Point Marls. Harris (1966) considers that only the upper fossiliferous sediments of this sequence are time-equivalent to the Blanche Point Marls.

Facies trends similar to those in the Willunga Embayment become apparent from [illegible] bores (Miles, 1952) in the Adelaide Embayment (Chart 7). In this area near the city of Adelaide marine organic sediments are overlain by shoreline dark sands and lignitic silts and clays (Glaessner, 1953b).

East and northeast of Adelaide marine sediments are gradually replaced by dark grey to black lignitic silts with interbedded pale grey to grey sands (Chart 7). Although only old subsurface data are available, these sediments probably grade to shoreline, fluvial and lignitic sediments. The greater part of these sediments may be approximately time-equivalent to the Soft Marl Member. However, fluviatile deposition of a much lesser extent, on the northwestern side of the Willunga Embayment probably continued during deposition of the Port Willunga Beds (p. 113) and the Adelaide Embayment may be similar. In the southwestern part of the Adelaide Embayment, the Taite bore (Miles, 1952) penetrated a similar sequence to that found in the Grange and Croydon bores. On lithological grounds and comparison of thickness within the Grange and Croydon bores, a minimum thickness of 150 feet (46 m) of clays and sands may be equivalent to the Soft Marl Member.

Thickness

The greatest thickness of sediments approximately time-equivalent to the Blanche Point Marls is found in the Adelaide Plains Embayment where over 250 feet (76 m) were penetrated by the Grange bore. The Grange, Croydon and Elizabeth bores are located in the structural axis of this Embayment. Near the structural axis of the Adelaide Embayment, bore records suggest a thickness greater than 200 feet (61 m) in the Taite bore. Near the structural axis in the Willunga and Noarlunga Embayments, bores penetrated a thickness of approximately 200 feet (61 m). The thickness variations of the Blanche Point Marls are shown on Charts 5, 6 and 7. They are caused by erosion, onlap and internal thinning in various members towards the sides of the embayments.

Sand equivalents of the Transitional Marl thin by onlap on a structural high separating the Willunga and Noarlunga Embayments. In the Adelaide Embayment similar relationships exist northeast of the city of Adelaide where the Banded Marl Member overlaps the Transitional Marl equivalents onto basement. The Banded Marl Member shows only minor internal thinning within the Noarlunga Embayment. In contrast, the Willunga Embayment shows internal thickening towards the axis of the embayment from 40 to 60 feet (12 to 18 m). The member is thickest in the Adelaide Plains Embayment where a thickness of 68 feet (21 m) is found along its axis. A similar thickness may be present near the structural axis in the Adelaide Embayment, as in the north flank of this Embayment the member is approximately 50 feet (15 m) thick. Charts 5 and 7 are designed to show the distribution of facies, particularly shoreline sediments inland on the northern flanks of the Willunga and Adelaide Embayments, and that near the coast marine sediments may have been continuous over structural highs separating these Embayments.

The greatest thickness variation in the Blanche Point Marls occurs within the Soft Marl Member. The member ranges in thickness from 45 to 57 feet (14 to 17 m) in coastal areas and 130 to 150 feet (40 to 46 m) near the structural axes in the Noarlunga and Willunga Embayments respectively. The southern margin of the Noarlunga Embayment reveals differential thickness trends. One mile (1.6 km) south of Moana Township on a wave-cut platform, the Soft Marls are about 70 feet (21 m) thick, whereas inland subsurface data indicate less than 50 feet (15 m).

Inland, near the northern and eastern margins of the Willunga Embayment the Soft Marls thin by intertonguing and lateral gradation to shoreline and fluviatile equivalents (Chart 5). Similar relationships are presented in Chart 7 on the northern margin of the Adelaide Embayment. North and northeast of Adelaide proper the marine member and equivalents thin finally to an erosional edge. In the Adelaide Plains Embayment subsurface data indicates thinning northwards between Grange bore and Hallions bore (Chart 6). Similar relationships probably occur from Elizabeth towards Gawler based on trends in the other embayments. In the Inkerman-Balaklava areas, about 35 feet (11 m) of quartz sands and arenaceous limestones represent marginal equivalents to the Blanche Point Marls.

Internal Features

Near the base of the Blanche Point Marls olive-green calcareous clays are laminated. Marine molluscs are oriented parallel to bedding and clay laminae have compacted around them. The remaining part of the Transitional Marl Member is massive, with fossils oriented at random. In the Banded Marl Member silicified bands and siliceous nodules accentuate the bold relief of the Member. The marine fauna includes abundant *Turritella aldingae* Tate mostly oriented at random as reported by early workers. This is also true for most of the Soft Marl Member. The Soft Marl Member for the most part is massive, but faint traces of laminated bedding have been recognized in some surface exposures.

Near the top of the Soft Marl carbonate nodules (Reynolds, 1953) contain numerous *Chlamys*. A thin band of argillaceous calcilutite 12 feet (3.6 m) below the top of the Member at the type area is found at a similar stratigraphic level in the wave-cut platform 1 mile (1.6 km) south of Moana in the Noarlunga Embayment. The upper 1.0 to 1.5 feet (30 to 46 cm) of the member is thin-bedded. Burrows are present throughout the whole of the formation.

Shoreline sediments east of Happy Valley Reservoir are thin-bedded. Numerous thin layers of sands and pebbles in carbonate cement are present, and often form small lenses and poor tabular cross-strata.

In the Willunga Embayment 1 mile (1.6 km) north of McLaren Vale a small scale paralic sequence is laminated to thick-bedded and includes gentle cross-stratified bedding (Text Fig. 7). Non-marine sediments show laminated bedding with minor, small-scale ripple and tabular cross-strata.

Constituents.

The major constituents of the Transitional and Banded Marl Members are calcium carbonate from the abundant marine fauna, secondary silica and clay. Reynolds (1953) noted that the Transitional Marls contain abundant microfossils throughout the member, but because of the gradational character between clays and foraminiferal limestones considered the sequence to represent marls. However, the greater part of the member corresponds to a foraminiferal coarse calcilutite in the sense of Folk (1959, 1962) or Calcisiltite of Sander (1967). The Banded Marls show alternating hard and soft layers dependent upon the variation of silica concentration (Reynolds, 1953). Thin sections show that clay minerals are often less than 25% in the soft layers and less than 5% in hard layers. Carbonate in the form of micrite and marine organisms is inversely proportional to the percentage of silica in the samples. Both the hard and soft parts of the member contain approximately equal numbers of mega- and microfossils. Micrite is more abundant in soft layers, particularly near the top of each layer. Silica is disseminated throughout these samples. Occasional siliceous concretions are present.

Sediments within the Soft Marl Member are essentially organic, calcareous clays. Carbonate content in the form of mega- and microfaunas is not greater than 33% for most of the member except for a hard band which contains 45% carbonate 12 to 15 feet (3.6 to 4.6 m) below the top of the member. In coastal sections carbonate gradually decreases to often less than 10% at the top of the formation. It is within this upper interval that <u>Limopsis chapmani</u> is common (Reynolds, 1953). This carbonate distribution is also found in the Noarlunga Embayment.

Siliceous sponge spicules are numerous in the Banded Marl Member and Soft Marl Member (Reynolds, 1953). In the latter they decrease in number in the upper part of the member where few are present. Glauconite is a common accessory mineral in the Blanche Point Marls (Reynolds, 1953). Glauconite maintains similar physical characteristics to these described in older formations (p. 51). Within the Banded Marls glauconite has in a few instances encrusted sponge spicules. Glauconite in the basal members renders a speckled appearance to light grey rocks. It is present within the Soft Marl Member, but not as common as in other members.

Mineralogy

X-ray techniques were applied to determine the clay mineralogy of the Blanche Point Marls. Secondary silica, which was at first thought amorphous opal in hand specimens, is crystalline opal or crystobalite-tridymite. The silica shows good crystalline structure in the lower two members whereas at different levels in the upper member poorly crystalline opal is present. An unidentified zeolite was mentioned by Ludbrook (1956, in Cochrane 1956) in a sample located near the top of the Blanche Point Marl equivalents in the Willunga bore. A zeolite is common in the Blanche Point Marls in lower parts of the Port Willunga Beds. X-ray diffraction of the fine fraction in representative samples indicates the presence of either heulandite or clinoptilolite. These two minerals are closely related forms whose optical properties and x-ray patterns are similar (Moiola and Wermund, 1966). Mumpton (1960) defined clinoptilolite chemically as the high silica member in the heulandite Group. Sodium and potassium appear dominant over calcium in clinoptilolite (Mason and Sand, 1960). Mumpton (1960) differentiates the two minerals by heat treatments. Clinoptilolite is stable to 700°C, whereas heulandite becomes amorphous at 450°C. Heat treatment of samples in the Banded Marl Member of the Blanche Point Marls indicates the presence of clinoptilolite. Clinoptilolite is also common in the middle part of the Soft Marl Member. Thin sections indicate pale yellow and colourless euhedral crystals. The mineral is associated with crystalline opal and montmorillonite.

Several workers consider that clinoptilolite is a secondary mineral formed through the dissolution of volcanic ash. However in this instance, clinoptilolite is probably formed through the dissolution of siliceous sponge spicules.

All montmorillonite samples examined were 12-16 Å basal reflection (001) minerals and responded to treatment with ethylene glycol, expanding to 17 or 18 Å by replacement of interlayer cations. These minerals were classified as smectites (montmorillonite-type minerals). The (060) reflection was then used to separate possible dioctahedral and trioctahedral varieties. All samples examined were dioctahedral. Montmorillonite is associated with dioctahedral glauconite through most of the formation. Thin beds of dominant montmorillonite are interbedded with the siliceous Blanche Point Marls in a road-and rail-cutting near Hackham. Elsewhere in siliceous sediments the mineral forms less than 10% of total rock samples. Within the Soft Marl Member mixtures of kaolinite and montmorillonite are common. The two minerals are variable in relative amounts except near the upper 12 to 15 feet (3.6 to 4.6 m) where kaolinite is consistently less, 2:1 to 5:1, than montmorillonite. Kaolinite is dominant with subordinate montmorillonite in shoreline and fluviatile sediments. Illite and chlorite occurs in trace amounts at all localities.

Chinamans Gully Beds

Definition and distribution

Reynolds (1953) applied the name Chinamans Gully Beds to a thin sequence of variegated silty and arenaceous clays, silts and quartz sands at Aldinga Bay. A bed of arenaceous clay overlying Reynolds' sequence was included within the definition of the Chinamans Gully Beds by Ludbrook (1956) because an unconformity separates this bed from the overlying Port Willunga Beds. For this reason, the usage of Ludbrook (1956) is followed here. Coastal outcrops in the Willunga and Noarlunga Embayments only are considered here whereas landward equivalents are discussed on pages 106 to 119.

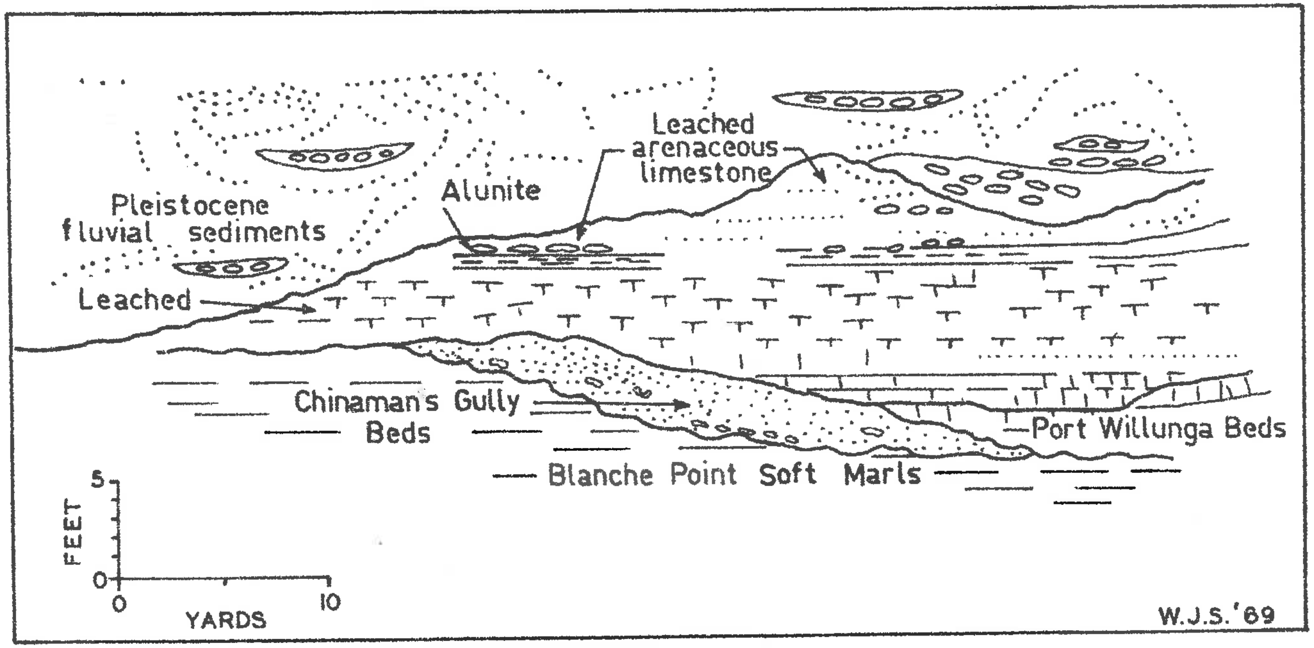
Within the basal, laminated, green and brown silty clays of the Chinamans Gully Beds, numerous leaves (Pl. 3, Fig. 3) have been preserved with carbonaceous cuticles at the type section. Near the middle of the formation, small scouring surfaces are located at the base of coarser sands. They occur in an alternating sequence of coarse and thin-bedded, grey-white and yellowish grey, very fine to fine quartz sands. Faint traces of laminae are present in the finer sands. These sediments are overlain by very thin beds of variegated, laminated, silty clays, clays and sands vertically grading to bright red and yellowish brown, gritty clay which contain Liesegang rings and occasional small scale, cross-strata (Reynolds, 1953). A thin, green, fossiliferous, arenaceous clay is present near the top of the Chinamans Gully Beds. It overlies the bright red clays whose upper surface contains burrows filled with green sediment. The gastropod _Turritella aldingae_ occurs within these clays. Arenaceous tests of foraminifera are dominant over calcareous tests (Reynolds, 1953).

The finely bedded variegated clays which are both continuous and lenticular and contain carbonaceous plant remains and occasional marine fossils particularly near the top of the sequence suggest a lagoonal environment with marine influence. The Chinamans Gully Beds abruptly overlie the Blanche Point Soft Marls.

Although erosion has removed a greater proportion of Tertiary sediments in the Noarlunga Embayment, the Chinamans Gully Beds are exposed near the mouth of the Onkaparinga River, immediately west of the footbridge (Wade, 1952), and on a wave-cut platform one mile (1.6 km) south of Moana Township (Map 5). At both localities dark brown and green silty clays and silts are similar to those at the type area.

At the northern locality, a ferruginous, poorly-sorted, quartz sand containing small quartz and quartzite pebbles occupies a cut and fill structure (Text Fig. 8). Although observation is possible only in two dimensions, it may have been part of a small stream channel which cut into the soft Marls. The Chinamans Gully Beds here are about 3 feet (90 cm) thick. To the south on the wave-cut platform, the Chinamans Gully Beds consist of olive green and brown, laminated and very finely bedded, silty and arenaceous clays, about 4 feet (1.2 m) thick. These clays contain intercalated 1 and 3 inch (2.5 and 7.5 cm) medium to coarse quartz sands which show a small amount of scouring along their basal surfaces. The Chinamans Gully Beds are unconformably overlain by the Port Willunga Beds and abruptly overlie the Soft Marls except for an unconformable cut and fill structure to the north.

Text Fig. 8 Exposures of Chinamans Gully Beds located immediately west of the footbridge over the Onkaparinga River, Noarlunga Embayment.


Leached
arenaceous
limestone
Alunite
Pleistocene
fluvial sediments
Leached
Chinaman's Gully
Beds
Port Willunga Beds
Blanche Point Soft Marls
FEET
5
0
0
10
YARDS
W.J.S.'69

TEXT FIG. 8

Port Willunga Beds

Definition, Lithology and Distribution

Reynolds (1953) applied the name Port Willunga Beds to a marine sequence of variable sequences of sediments. At Aldinga Bay in the Willunga Embayment (Text Fig. 1) a thin sand containing pebbles unconformably overlies the Chinamans Gully Beds (Ludbrook 1956).

Between Aldinga Creek and Chinamans Gully the basal sand is overlain transitionally by moderately-sorted, cross-stratified bryozoal calcarenites, max. 9 feet (2.7 m) thick. Towards Chinamans Gully the bryozoal calcarenites laterally grade to pale grey, moderately to well sorted, subrounded to rounded quartz sands with only occasional bryozoal fragments. The bryozoal calcarenites are overlain by about 30 feet (9 m) of poorly sorted, yellowish grey and buff fossiliferous argillaceous clays and quartz sands. They are interbedded with thin, green and brown clay beds often containing carbonate nodules (Reynolds, 1953). Although there are numerous vertical gradations, lateral gradation in these sediments is less common. These sediments are followed by ledge-forming, yellowish grey to green, clays, biomicrites and calcarenites often containing abundant sponge spicules. They often contain layers and nodules of secondary silica (Reynolds, 1953). Within these sediments bryozoal fragments increase in inverse proportion to clay within less resistant interbeds, until cross-stratified, yellowish grey and pale brown, moderate-to well-sorted, bryozoal calcarenites and calcirudites predominate (Text Fig. 1). The siliceous sequence is about 45 feet (14 m) thick whereas the thickness of the overlying bryozoal sequence is about 35 feet (11 m). The total thickness of the formation here is about 120 feet (37 m).

The Port Willunga Beds are unconformably overlain by Upper Pliocene limestones; the erosional surface is an angular unconformity (Reynolds, 1953). The thickness of bryozoal sediments at the top of the formation was computed from thicknesses in coastal cliffs and at times when sand was removed from the coastal beach. At Aldinga Bay the Port Willunga Beds were deposited during the latter part of the Upper Eocene and in part during Oligocene (Ludbrook and Lindsay, 1966; Lindsay, 1967). Reynolds (1953) did not define the top of the Port Willunga Beds and several workers have extended the formation to include Lower and Middle Miocene sediments unconformably underlying Pliocene or Pleistocene sediments in the subsurface, and in a few instances, exposed on the sides of the embayments, where the sediments show lithological uniformity.

On the southern margin of the Willunga Embayment folded, bryozoal calcarenites in coastal cliffs were described by Howchin (1911). These sediments form a small fold north of Mt. Terrible Gully. Glaessner (1953b) described these flexured sediments both here and further south where they dip steeply over Cambrian sediments. Further, Glaessner noted a thin, transgressive, quartz sand at base and fissures in Cambrian shales filled in with hard, pink, bryozoal calcarenites. In a small creek where the north trending coast swings to the west-southwest, yellowish grey, pebbly sands grade vertically within 3.0 feet (90 cm) to arenaceous, bryozoal calcarenites. The calcarenites often contain scattered pebbles of Cambrian Heatherdale Shale. South of Sellick Beach, bryozoal sediments are of Lower Miocene age (Wade, 1964) and are younger than bryozoal calcarenites exposed at the top of the type section, six miles (9.6 km) to the north.

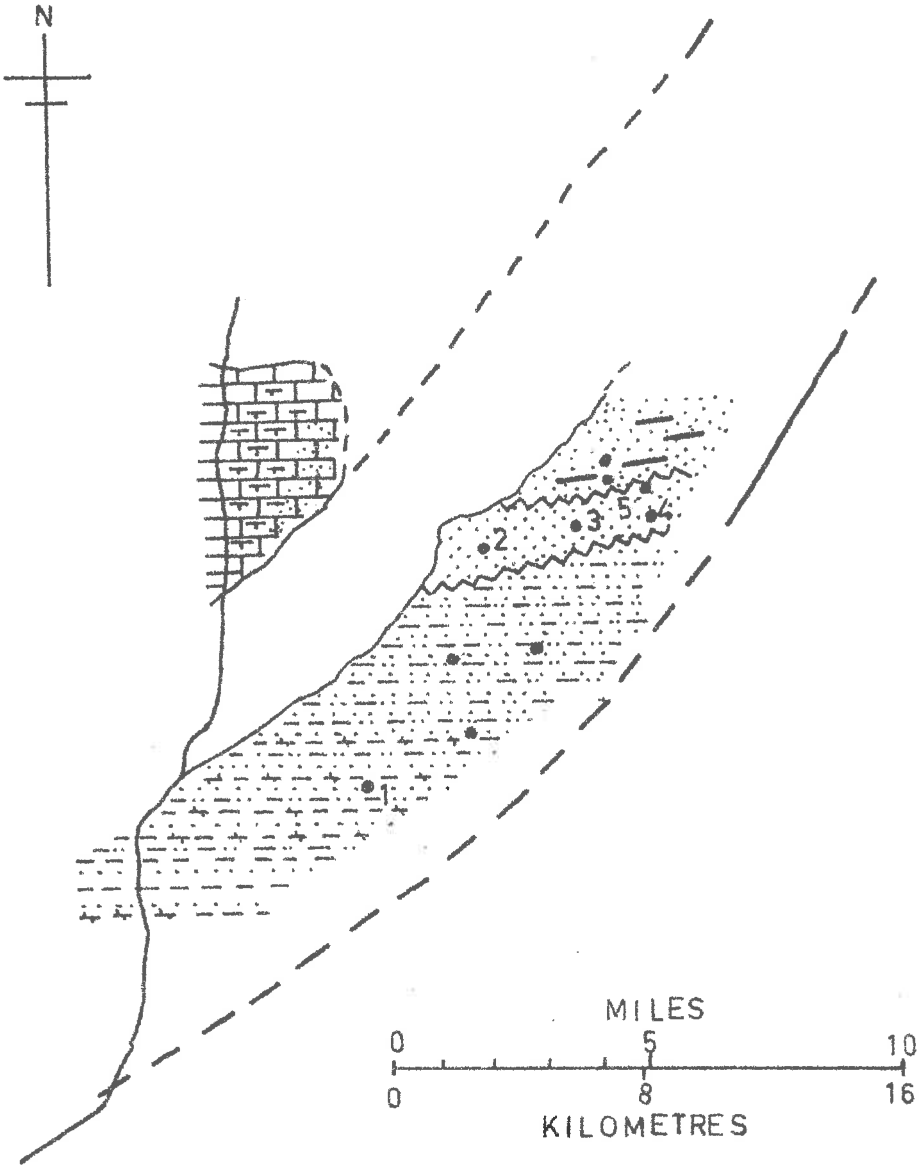
Inland, near the structural axis of the embayment, the Willunga Bore No. 1 penetrated a sequence of calcareous sands equivalent in part to the coastal sequence. The marine, sandy facies of the Port Willunga Beds (Woodard, 1952; Glaessner, 1956) is shown in Chart 5. Grey and drab green, calcareous, poorly-sorted, silts to coarse sands from 335 to 390 feet (102 to 11 m) are overlain by grey, calcareous very fine to fine sands from 250 to 335 feet (76 to 102 m); these correspond in part to Upper Eocene and Oligocene sediments in the type area (p. 86). The hard, silicified sediments on the coast have given way in part to very fine and fine, calcareous sands and clays in the bore. It is noteworthy that bryozoa and sponge spicules also are common in this interval at similar levels to those in the type area. Pale yellow and brown calcareous, very fine to medium sands with interbedded fossiliferous quartz pebble sands and hard, arenaceous calcilutites are found between 115 and 250 feet (35 to 79 m) in the Willunga bore. They are partly correlated with Lower Miocene bryozoal calcarenites south of Sellick Beach (Wade, 1964). Elsewhere in the Willunga Embayment erosion has limited this sequence to the axial parts of the embayment.

On the northern and northeastern margins of the Willunga Embayment the basal sediments of the Port

Willunga Beds consist of 40 to 60 feet (12 to 18 m) of marine, dark ochre-yellow, glauconitic fine to medium, quartz sands (Text Fig. 9). In the H.B. 420 bore thin limestone bands are interbedded in ochre-yellow sands (Woodard, 1952), whereas in the McGeorge bore only sparingly fossiliferous, dark yellowish grey, fine to medium quartz sands are present. In both bores they unconformably overlie fluviatile sediments. Immediately east of the McGeorge bore and near the arcuate structural axis of the embayment, the Whitstone bore contains a sequence of dark yellowish grey lignitic pebbly sands interbedded with well-sorted quartz sands containing a few glauconitic pellets. They probably represent beach and lagoonal fluviatile environments. No clear-cut unconformity is recognized at the base of this sequence although unconformities are likely from the nature of the environment.

About one mile (1.6 km) northwest of the Whitstone bore, these sediments probably grade to lignites and pale yellow sands found in the Adams bore. Sediments within closely spaced bores indicate an inland bay. The basal ochre sand sequence is overlain by about 50 feet (15 m) of calcareous, arenaceous, glauconitic clays with interbeds of silicified, Text Fig. 9 Facies distribution of the lower beds of the Port Willunga Beds, Willunga Embayment. Bores individually referred to in text are numbered.

TEXT FIG. 9



1. Willunga Bore No. 1
2. H.B. 420 Bore
3. McGeorge Bore
4. Whitstone Bore
5. Adams Bore
6. McLaren Vale

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arenaceous, calcilutites in the H.B. 420 bore. These sediments contain sponge spicules and the gastropod Turritella aldingae and were correlated by Woodard (1952) with the Blanche Point Marls. Indeed, these sediments, especially in the H.B. 420 bore, appear plysically similar to the Blanche Point Marls. However, micropalaeontological examination of these sediments suggests an Oligocene age (p. 203) and they actually correlate with the Oligocene, silicified calcarenites and calcilutites within the Port Willunga Beds at Aldinga Bay. On the northeastern side of the embayment they are replaced by poorly fossiliferous, grey quartz sands, with thin, glauconitic sands intercalated. These sediments thin to an erosional edge on the northern and eastern margins of the embayment.

In a road-cut 2.5 miles (4 km) north of McLaren Vale Township, about 35 feet (11 m) of mottled green, maroon and dark ochre-brown, fine to medium grained fossiliferous, glauconitic sands are overlain by about 9 feet (2.7 m) of reddish grey and pale grey bryozoal calcarenites and silicified biogenic calcilutites. The sediments are very weathered. They are correlated with the Port Willunga Beds in the H.B. 420 bore (Chart 5). About 1.5 miles (2.4 km) west of Blewett Springs, patches of fossiliferous, ferruginous, arenaceous conglomerates occur at an elevation of about 500 feet (153 m). They were placed by Tate and Dennant (1896) in the Upper Eocene. They are here correlated with the basal ochre-yellow sands of the Port Willunga Beds.

Along the northern and northeastern sides of the Willunga Embayment, the ochre-yellow sands and arenaceous calcilutites of the Port Willunga Beds are preserved in an erosional escarpment trending east-west and facing south. The sediments have a regional dip of less than 1° trending to south in the western area and southwest in the eastern area (although locally small folds may show dips up to 6°). Erosion to deeper levels between McLaren Vale and McLaren Flat has removed the Port Willunga Beds and underlying sediments between the northern side and the structural axis of this embayment (Chart 5).

In contrast to the Willunga Embayment, the Port Willunga Beds have been preserved only within the synclinal axis of the Noarlunga Embayment. On the northern flank of the syncline Upper Eocene and Oligocene sediments of an equivalent age to the type section occur adjacent to the estuary of the Onkaparinga River and extend along the coast southwards towards Moana Township for about 1.5 miles (2.4 km) where they dip below sea level (Text Fig. 9, Chart 2). About ½ mile (0.8 km) north of Moana Township the Port Willunga Beds reappear in the form of a gently dipping fold. These sediments range in thickness from an erosional feather edge to about 140 feet (43 m). On the southern flank over 130 feet (40 m) of Port Willunga Beds are exposed on the wave-cut platform one mile (1.6 km) south of Moana Township (Map 5).

Immediately west of a footbridge on the south bank of the Onkaparinga River, the Port Willunga Beds unconformably overlie the Chinamans Gully Beds. At the base of the formation a thin transgressive dark yellowish grey quartz sand overlies a slightly irregular surface (Text Fig. 8). It is overlain by grey to brown bryozoal calcarenites, minimum 6.5 feet (2 m) thick, with interbeds of yellowish grey calcareous sands. A thin bryozoal limestone containing numerous lamellibrachs (Chlamys) is found in upper levels. The calcarenite is similar to the bryozoal calcarenite and sand near the base of the formation at Aldinga Bay. From the locality of Chinamans Gully Beds to the mouth of the Onkaparinga River, the bryozoal calcarenites are overlain successively by about 50 feet (15 m) of pale grey, grey-white and olive-grey marls (argillaceous foraminiferal calcarenites and calcilutites). Thin beds of laminated green clays and lenses of pellets rarely occur in lower parts of this sequence. In contrast, in the wave-cut platform south of Moana, the bryozoal calcarenite facies is absent. Thin glauconitic sands unconformably overlie the Chinamans Gully Beds. They are overlain by about 60 feet (18 m) of coarse biogenic calcilutites similar to the composite section to the north. At both localities the upper 25 to 35 feet (8 to 11 m) of the calcilutite sequence is in part silicified and forms thin ledges within less resistant calcilutites. The interval of calcilutites is similar to the lower beds of the Blanche Point Marls. They contain a few bryozoa and the gastropod Turritella aldingae. Except for the basal bryozoal calcarenites in the composite section to the north, the calcilutite sequence is not identical with the lower 40 feet (12 m) of variable sediments at Aldinga Bay, although they are time-equivalents.

At both localities in the Noarlunga Embayment, the calcilutite sequence is gradationally overlain by a sequence of sediments which are variable in lithology. Near the base of the sequence a green and grey calcareous clay is silicified and forms parts of a prominent ledge. It is overlain by pale grey, dark yellowish grey bryozoal calcilutite interbeds with pale grey and yellowish grey, arenaceous and argillaceous calcilutites, bryozoal calcilutites and calcarenites, and occasionally thin beds of calcareous sands. Concentrations of secondary silica into nodules and layers form resistant ledges within the sequence. Micrite and argillaceous sediment decreases in inverse proportion with an increase in bryozoal fragments towards the top of the sequence. They finally grade vertically to pale grey and yellowish grey moderately-sorted bryozoal calcarenites and calcirudites which form the upper part of the formation both here and at Aldinga Bay.

The lower part of the Port Willunga Beds at its type area is time-equivalent to organic calcareous clays and silts in the subsurface of the Adelaide and Adelaide Plains Embayments. These sediments transitionally underlie silicified calcarenites in the Grange, Croydon and Hallions bores. Lindsay (1967) notes that these calcarenites are fairly widespread in the Adelaide Plains. The silicified calcarenites may be time transgressive between the Grange and Hallions bore west of Two Wells Township (Chart 6). The lower clays decrease in foraminifera and those present are usually depauperate, but they show more marine influence than the underlying beds. In the Elizabeth bore both the lower clays and the siliceous limestones are replaced by dark grey and brownish grey, fossiliferous, argillaceous sands and silts and arenaceous silts and clays. Sediments between 750 and 1,003 feet (229 and 306 m) occur at similar stratigraphic levels to the soft Marl Member of the Blanche Point Marls, the lower part of the Port Willunga Beds and the siliceous limestone. The changes in lithology are not unexpected since similar facies relationships have been encountered towards the sides of the Willunga Embayment. In the Adelaide Embayment silicified calcarenites or limestones have been reported in the subsurface by Howchin (1935) and Miles (1952) both on the northern and southern margins of the embayment. They occur at the southwest part of the embayment in Hundred of Noarlunga in the S.S. Ivemey bore No.74 between 185 and 260 feet (56 and 70 m) and near the base, 500 feet (152 m), in the Oaklands bore No. 30 (Chart 2). Howchin (1935) described "cherty" limestones in the Black Forest bore between 160 and 265 feet (49 and 81 m) located southwest of the city on the northern margin of the embayment.

In the latter bore, Howchin described marine black clays probably equivalent to both the Blanche Point Marls and lower part of the Port Willunga Beds. In the Taite bore No. 214 (Miles, 1952), an undifferentiated sequence of dark sands, silts and clays between 330 and 684 feet (101 and 209 m) are probably equivalent to lower parts of the Port Willunga Beds and possibly the upper part of the Soft Marl Member of the Blanche Point Marls. No distinction of the siliceous interval can be made from the bore data. From available subsurface data (Miles, 1952; Steel, 1962) these sediments thin to a feather edge under the city of Adelaide. Steel (1962) recorded a 2 foot thick (61 cm) bed in the subsurface located near the centre of the city of Adelaide, which he correlates with the siliceous interval, in the Croydon bore. Steel considered sediments below the siliceous interval as Blanche Point Marl time- and rock-stratigraphic equivalents before an Upper Eocene age was proposed for the Port Willunga Beds by Lindsay (1967). Subsurface data are not available to delineate trends in the structural axis from the Taite bore to inland areas. It is probable that the sediments follow synclinal trends similar to those found in the Willunga

Embayment. The possibility exists that towards the eastern and southern sides of the Adelaide Embayment these sediments partly grade to shoreline and fluviatile sediments.

Pale grey, grey-white and yellowish bryozoal calcarenites and calcirudites are fairly widespread in the Adelaide Plains and Adelaide Embayments (Charts 6 and 7). Several workers since the latter part of the 19th century have recognized these sediments. In the Adelaide Plains Embayment the bryozoal sediments are about 500 feet (152 m) thick in the Grange and Croydon bores whereas in the Adelaide Embayment they are about 380 feet (116 m) thick in the Oaklands bore (Chart 2). Erosion accounts for the difference in thicknesses between the two areas. It has limited these sediments to westward portions of the Adelaide Embayment. In the Adelaide Plains Embayment they thin by erosion and onlap northwards towards the Inkerman-Balaklava area (Chart 6).

Moderate-to well-sorted Oligocene bryozoal calcarenites and calcirudites near the top of coastal sequences in the Willunga and Noarlunga Embayments are of the same age as poorly-sorted arenaceous, micritic calcarenites occurring near the base of the sequence between 1020 and 971 feet (311 and 296 m) in the Grange bore. They grade upwards to arenaceous very fine to medium calcarenites often containing glauconite. Silt in the form of both quartz and skeletal carbonate in part fills voids between secondarily cemented bryozoal or molluscan fragments. Secondary calcite or sparite growths fill parts of the voids. Sparite which is present in all samples is more common between 710 and 860 feet (216 - 262 m). Between 666 and 680 feet (203 and 207 m) pale and dark grey very finely arenaceous and silty clays and silts are present within the bryozoal calcarenites. Lindsay and Shepherd (1966) have applied the name Munno Para Clay Member of the Port Willunga Beds to these sediments and have shown the lateral continuity or distribution of these sediments from the western part of the Adelaide Embayment towards the township of Gawler in the Adelaide Plains Embayment. The Munno Para Clay Member is shown in Chart 6 between the Grange and Hallions bores. Very fine pale yellowish grey to pale grey fossiliferous calcarenites overlie the Munno Para Clay Member in the Grange bore between 666 and 550 feet (203 and 161 m).

The bryozoal calcarenite facies extends north of Grange bore to west of Two Wells Township, where

160 feet (49 m) of sediments was penetrated by the Hallions bore (Chart 6). In the Balaklava-Inkerman area Steel (1961) recognized Lower Miocene fossiliferous sands, pebble sands and white microcrystalline limestone which overlie probable Oligocene marine green arenaceous clays, the "Port Julia Greensand". The name Port Julia Greensand is not used here in this area (p. 155). Either these clays or the overlying Lower Miocene sediments unconformably overlie time-equivalents of the Blanche Point Marls. In the Grange bore the bryozoal facies mostly grades to pale brownish grey, pale grey and yellowish grey, foraminiferal and bryozoal, quartz sands towards the northeastern side of the Adelaide Plains Embayment. Bryozoal calcirudites and calcarenites are interbedded with these sediments. In the Elizabeth bore, 750 and 370 feet (229 and 113 m), the sequence is predominantly interbedded clay, silts and sands. Fossiliferous sands interbedded with black, carbonaceous and lignitic sediments near the base of this sequence may indicate marginal conditions (Dalgarno, 1961). The Munno Para Clay Member is present both near the top of the Grange and the Elizabeth bores (Lindsay and Shepherd, 1966). Howchin (1912) showed that a surface outcrop of fossiliferous gravels and sands at an

elevation of 400 feet (122m) just east of Gawler Township (Map 1) was probably a shoreline deposit. Glaessner and Wade (1958) substantiated this by discovering Teredo borings in silicified tree trunks, and correlated the deposit to the Port Willunga Beds by the pelecypod Eotrigonia semiundulata Tate. The latter fossil is present in a surface outcrop of bryozoal calcarenites at Red Banks on the River Light, 15 miles (24 km) northwest of Gawler Township (Ludbrook, 1959).

South of the Willunga Embayment in the Myponga Valley (Map 1) the Myponga bore penetrated 385 feet (117 m) of dark yellowish grey and pale grey bryozoal calcarenites, interbedded with quartz sands, silts, clays and lignites, between 276 and 661 feet (84 and 201 m). The basal 159 feet (48 m) are dark yellowish grey to grey hard bryozoal calcarenites which contain variable amounts of sparite. These bryozoal calcarenites are followed by 81 feet (25 m) of interbedded silty and arenaceous clays, silts, quartz sands and lignites which contain quartz grains. The lignites, 8 feet (2.4 m) thick, are found near the top of this interval followed by coarse quartz sands. About 130 feet (40 m) of pale grey, bryozoal calcarenites overlie the quartz sand and clay sequence with an interbedded thin, 2.0

foot (61 cm) marine lignitic clay near the top of the bore. The calcarenites overlie Permian sediments (Mining Review, 53: Campana and Wilson, 1954). Wade (1964) correlates the basal part of this sequence with Lower Miocene sediments exposed in the Willunga bore and Sellick Beach area. The whole sequence is approximately time-equivalent to the Lower Miocene bryozoal calcarenites in the Adelaide Plains Embayment.

About 7 miles (11.2 km) southwest of Myponga Township Howchin (1911) recognized a hard pink bryozoal limestone in the Hindmarsh Tiers area. The outcrop of this is approximately 750 feet (227 m) above sea level. Campana and Wilson (1954, Pl. XI) relate the outcrop to subsurface bryozoal sediments in the Hindmarsh Valley. Thomson and Horwitz (1962) show an outcrop of bryozoal limestone 2.3 miles (3.7 km) northeast of the latter locality at an elevation of about 1000 feet (305 m). Both outcrops show grey and pink, well-sorted calcirudites. Pores are completely infilled by sparite. Glaessner (1953b) has correlated these sediments with the Miocene sequence.

Internal Features and Constituents

Sedimentary and organic structures. In the coastal sequences bryozoal calcarenites and calcirudites often show medium scale, planar (wedge and tabular) cross-strata. Near the base of the Port Willunga Beds at Aldinga Bay a planar tabular cross-set about 3 feet (90 cm) thick shows individual laminae dipping approximately 27° to the north. ~~Horizontal laminae are situated at right angles to the cross-strata.~~ This type of cross-strata is formed by straight current ripples (J.R.L. Allen, 1966). Echinoid trails are common on its upper surface (Pl. 7, Fig. 2). Burrows penetrate through successive laminae. Bryozoal-rich sediments in the upper parts of the Port Willunga Beds contain planar (wedge and tabular) cross-strata at Aldinga Bay and coastal sequences to the north. Individual laminae are inclined at low angles, 15 to 20°. Small scale ripple marks are rare in these sediments. Although bias may result from observation in only north-south coastal exposures, the main direction of current flow is to the north. In a small fold at Sellick Beach in the Willunga Embayment, small scale planar, tabular cross-strata dipping at about 22° show a bimodal south and north distribution. These Lower Miocene sediments are younger than the Upper Eocene and Oligocene sediments in coastal sections to the north. In all coastal areas bryozoal calcarenites and calcirudites interbedded with cross-strata sets are thin-bedded.

About one mile (1.6 km) south of Sellick Beach slump structures are present in highly folded bryozoal limestones (Howchin, 1911; Glaessner, 1953b). Small fold-like slumps are shown in Plate 8, Fig. 1. Siliceous layers and nodules are present in these structures. Occasional layers of silica are fractured near the crest of some slumps which indicate fairly early deposition of silica since the slumps are intraformational structures. These structures suggest that during the deposition of bryozoal limestones in this area movements were taking place along the Willunga Fault (Glaessner, 1953b). Small asymmetrical folds with small displacements of individual beds along small faults (Pl. 8, Fig. 2) may also be due to movements along the Willunga Fault. Several truncated surfaces occur within these bryozoal limestones (Pl. 8, Fig. 3). They could have formed during occasional storms but periodic uplift in this unstable area during deposition of these sediments is the likely cause.

The Port Willunga Beds contain a mineral suite similar to the Blanche Point Marls. Clinoptilolite, poorly crystalline cristobalite or opal, montmorillonite and glauconite are present in siliceous rocks whereas the latter two minerals are only present in variable amounts in other parts of the formation. Among many forms of glauconite found in the Port Willunga Beds, glauconitic pellets are occasionally present where clay has infilled zooecia within bryozoans.

Nonmarine Sediments of the Eastern Margins and Upland Areas

General Statement

The inland Tertiary fluviatile sediments are variable but their composition and sedimentary structures are like those of the North Maslin Sands. Unconsolidated, poorly-sorted quartz gravels and pebble to cobble conglomerates with ferruginous and sometimes siliceous cement are often found in lower parts of the sequence. Conglomerates are usually lenticular in shape and represent channel-lag deposits. The pebbles and boulders show a variable roundness and indented percussion marks.

In Tertiary sands deltaic cross-stratifications have been illustrated by Dalgarno (1961), Campana (1955) and Olliver (1967b) in Upland Areas east of the Adelaide Plains Embayment. In most cases these structures represent truncated channel-fills. Fine to coarse quartz sands form large scale, planar (tabular and wedge) and medium scale, trough (lenticular) cross-strata. Lenticular, laminated, pale grey silts, silty clays and very fine sands probably have been deposited in ponds on the flood plains. Laminated lignites and arenaceous silty clays have been reported in the subsurface by many workers. On the northeast side of the

Adelaide Embayment, one of these lignites was exposed in Denton's sand quarry at Golden Grove. The lenticular lignite contains carbonaceous tree stumps and numerous pieces of bark. Leaves are much rarer in this lignite than in the lignite exposed in the Noarlunga sand quarry. Well-sorted pale grey quartz sand often forms very fine thin beds and laminae in carbonaceous clay and lignite. Dark brown to black lignite is often laminated. The laminae are interrupted and wavy where carbonized wood is preserved.

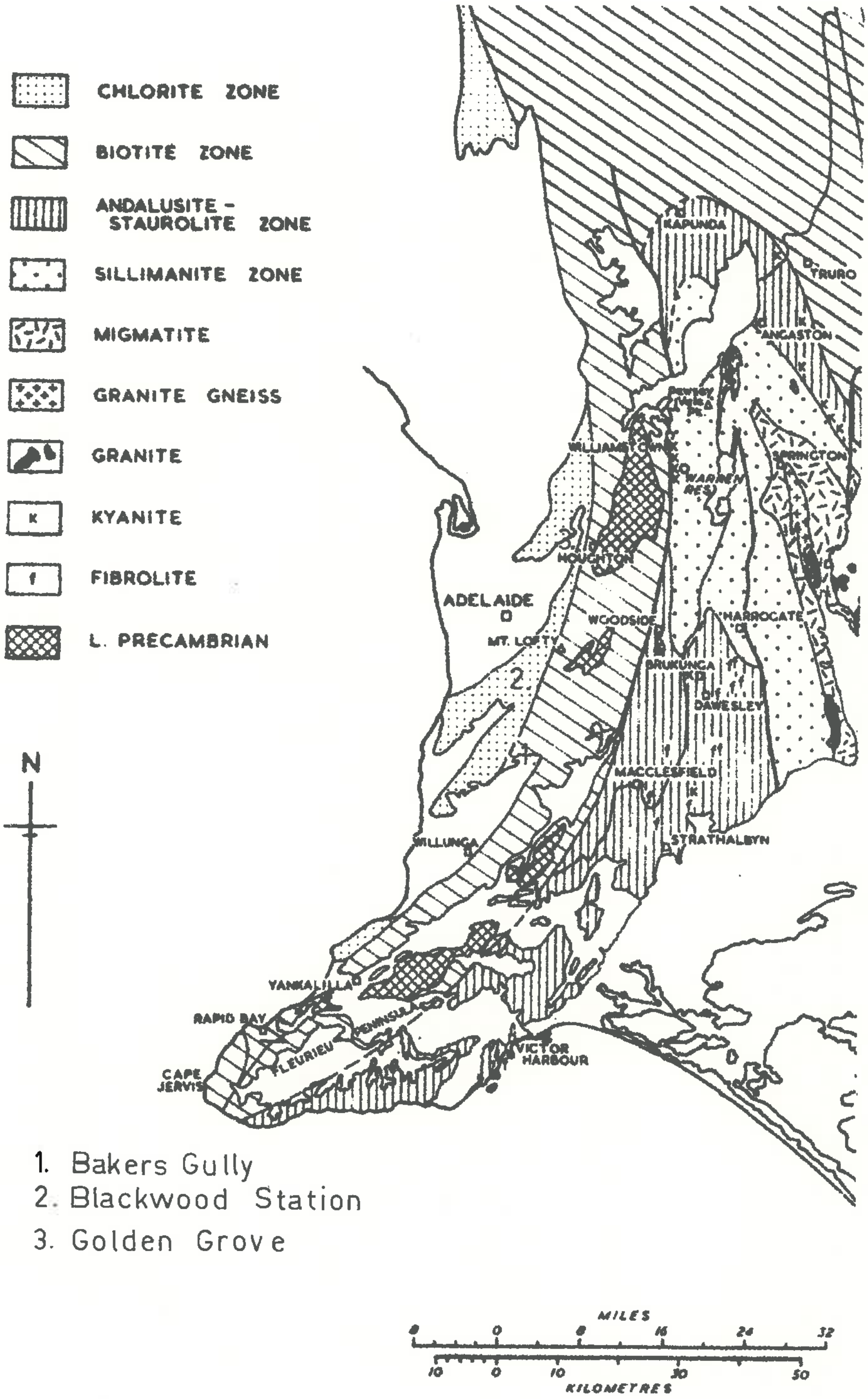
Mineral assemblages within most fluviatile sediments (Dalgarno, 1961) are similar to the North Maslin Sands (p. 35) except for the mineral staurolite which forms up to 5% in some samples and is often twinned. Although other minerals reflect local sources in the surrounding hills, staurolite could be derived only from two possible source areas of metamorphic rocks in the Mt. Lofty Ranges (Text Fig. 10); the northerly occurrence lies north and east of the Barossa Valley and the southerly forms a north-south area east of the Willunga Embayment (Offler and Fleming, 1968).

Distribution

On the northeastern margin of the Willunga

Text Fig. 10 Metamorphic zones in basement rocks in the Mt. Lofty Ranges. From Offler and Fleming, 1968.

TEXT FIG. 10


CHLORITE ZONE
BIOTITE ZONE
ANDALUSITE - STAUROLITE ZONE
SILLIMANITE ZONE
MIGMATITE
GRANITE GNEISS
GRANITE
K KYANITE
f FIBROLITE
L. PRECAMBRIAN
N
KAPUNDA
TRURO
ANGASTON
WILLIAMSTOWN
WARREN RES.
SPRINGTON
HOUGHTON
ADELAIDE
WOODSIDE
HARROGATE
MT. LOFTY
BRUKUNGA
DAWESLEY
MACCLESFIELD
STRATHALBYN
WILLUNGA
YANKALILLA
RAPID BAY
FLEURIEU
PENINSULA
CAPE JERVIS
VICTOR HARBOUR
1
2
3
1. Bakers Gully
2. Blackwood Station
3. Golden Grove
MILES
8
0
8
16
24
32
10
0
10
30
50
KILOMETRES

Embayment, some exposures of Tertiary fluviatile sediments occur in the vicinity of Bakers Gully (Text Fig. 10). East of the Willunga Embayment in the Meadows Valley, they were penetrated in the Sadlier's bore about one and a half miles (2.4 km) southwest of Meadows township. Howchin (1933) noted erosional remnants northeast of the Noarlunga Embayment in a railway-cutting at Blackwood station (Text Fig. 10). About nine miles (14 km) north-east of Adelaide in the Adelaide Embayment, fluviatile sediments are exposed in several sand quarries in the Highbury east- Tea Tree Gully area, immediately east of Gawler township and in the Barossa Valley. Dalgarno (1961) applied the name Rolands Flat Sands to the "Lower Tertiary" sands and gravels in the Barossa Valley.

Although fluviatile sediments are reported from many isolated outcrops in the Mt. Lofty Ranges, only those closely related to the embayments of the St. Vincent Basin or where ages have been determined are considered here. Subsurface data and surface exposures in these areas show an irregular basement relief. From both surface and subsurface data the greatest thickness, 150 to 200 feet (46 to 61 m), is located northwest or west of faults in the Adelaide Embayment, Willunga Embayment and Barossa Valley. The sediments thin to feather edges by erosion and overlap of basement. Overlapping relationships are recognized within general, fining-upward sequences. Conglomerates and gravels often are found in topographic lows whereas finer grained sediments overlap highs. However, there is general overall coarsening of sediments towards the northeast in the embayments and the Barossa Valley. The fluviatile sediments are overlain unconformably by probable Pliocene to Recent fluviatile sediments (Glaessner, 1955). Often laterites are formed near the top of the basal fluviatile sequences (Dalgarno, 1959, 1961 and Olliver, 1967). Immediately east of Gawler Township fluviatile sediments are overlain by littoral deposits (Glaessner, 1955).

Age

For many years, several workers have based the ages of marginal and upland fluviatile sediments on stratigraphic position, common sediment-type, wood and leaf impressions. Several recent workers have correlated the Middle Eocene North Maslin Sands with fluviatile sediments on the northeastern and eastern margins of the Willunga and/or Adelaide Embayments (Woodard, 1952; Glaessner, 1953b; Ludbrook, 1956; Glaessner and Wade, 1958; and Olliver and Weir, 1967). Dalgarno (1961) following Glaessner (1955) assumed a Lower Tertiary age for the Rolands Flat Sands in the Barossa Valley and correlated the sediments with those of the Highbury-east Tea Tree Gully area.

Lignite samples were submitted to Mr. Wayne Harris, Department of Mines, S.A. for palynological examination from the following areas: (1) the Whitstone, Adams and McGeorge bores located 2 to 3 miles (3 to 5 km) southwest of Bakers Gully in the Willunga Embayment, (2) the Sadlier bore located 1½ miles (2.4 km) west-southwest of Meadows Township and (3) Denton's sand quarry near Golden Grove in the northeastern part of the Adelaide Embayment (Text Fig. 10).

On the margins of the Willunga and Adelaide Embayments the lignites are considered by Harris (pers. comm.) to be of Upper Eocene age; distinctly younger than the Middle Eocene North Maslin Sands. In the Willunga Embayment, micropalaeontological examination of sediments interbedded near the top of the sequence suggests a time range of Upper Eocene to lowermost Oligocene (Chart 5). In contrast to the Upper Eocene to lowermost Oligocene sediments on the northeast margin of Willunga Embayment, lignitic sediments from the Sadlier bore in the Meadows Valley are of Mid-

Tertiary age. In the Barossa Valley Harris and Olliver (1965) have shown that lignitic clay balls in the Rolands Flat Sands overlying basal conglomerates are also of Mid-Tertiary age. Immediately east of Gawler township on the eastern margin of the Adelaide Plains Embayment, at least an upper limit of age can be established for fluviatile sediments that are gradationally overlain by Upper Oligocene or Miocene littoral sediments. The gradational contact suggests that the fluviatile sediments are only slightly older than the overlying littoral sediments.

Correlation

The names Bakers Gully Sands and Golden Grove Sands are already applied informably to fluviatile sediments on the northeastern margins of the Willunga and Adelaide Embayments respectively, and are used here in correlating these sediments to seaward parts of the embayments. Fortunately, new bores in the Willunga Embayment were put down in key positions. In the Adelaide Embayment, bore data (Miles, 1952) and surface outcrops of marine sediments assist in reinterpretation of the stratigraphy.

In the Willunga Embayment it has been shown previously that parts of the marine Blanche Point Marls and Port Willunga Beds laterally grade and intertongue with shoreline and lagoonal sediments (Chart 5). The Bakers Gully Sands contain a greater proportion of lignites, lignitic clays interbedded with fine and coarse quartz sands towards the structural axis of the Willunga Embayment. These sediments and marine sediments intermittently filled the remainder of the embayment. The distribution of shoreline, lagoonal sediments and the Blanche Point Soft Marls indicates an offlapping relationship towards the Willunga Bore No. 1 (Chart 5). In this bore a small scale paralic sequence is intercalated in the marine sediments equivalent to the Blanche Point Marls and Port Willunga Beds. Glaessner (1953b, 1956) correlated these sediments with the predominantly non-marine Chinamans Gully Beds exposed in coastal cliffs at Aldinga Bay. On the basis of foraminifera within parts of the sequence in Willunga Bore No. 1, Ludbrook (1956) showed that the sediments were paralic on a small scale, and substantiated Glaessner's correlation. Actually the thickness of these sediments is hard to determine because they appear gradational with underlying and overlying sediments, so a thickness of 26 feet (8 m) between the depths of 400 and 426 feet (122 to 130 m) is based on mainly minor physical changes. Inland along the structural axis of the embayment to the Whitstone bore, the Bakers Gully Sands intertongue with the basal parts of the Port Willunga Beds. Numerous disconformities are probably present in the sequence. On the other hand on the more northern margins in the E.B. 420 bore and McGeorge bores the fluviatile sediments are overlain unconformably by the basal marine sands of the Port Willunga Beds (Chart 5).

Sprigg (1946) correlated erosional remnants in a railway-cut near Blackwood Station with the "freshwater" sediments, now North Maslin Sands, in the Noarlunga Embayment, on lithology and stratigraphic position. The age of these sediments cannot be determined. They are physically similar to the other fluviatile sediments and overlain by Pleistocene to Recent sediments in the area. They are exposed 800 to 900 feet (243 - 273 m) above sea level.

From the northeast margin of the Adelaide Embayment towards the city of Adelaide, facies relationships between the Golden Grove Sands and the Blanche Point Soft Marl equivalents are similar to those in the Willunga Embayment (Chart 7). On the central, northern and northeastern parts of the Adelaide Embayment, possible correlatives of parts of the Port Willunga Beds have been removed by erosion. If relationships between the marine Port Willunga Beds and fluvial Golden Grove Sands are similar to the relationships in the Willunga Embayment, fluviatile and small scale paralic sediments will be found inland near the structural axis of the Embayment. Published subsurface data is limited to northern and western parts of the embayment. However, about three miles (4.8 km) immediately east of Adelaide, the M.T.T. bore No. 217 (Miles, 1952) penetrated sands, clays and lignites 350 feet (107 m) thick between 385 and 667 feet (187 and 203 m). No fossils or "limy" sediments were recorded so they may be nonmarine and equivalent in part to the Blanche Point Soft Marls and possibly lower parts of the Port Willunga Beds. These sediments overly "chalky" and green clays which are probably equivalent in part to the Blanche Point Banded Marls. The Banded Marls have been exposed by excavations at Adelaide and southwest of Hope Valley Reservoir. In this vicinity, bore logs are fairly consistent in terminology used for sample descriptions. Glaessner (1953b) noted an upper lignite sequence in the vicinity of the city. The Golden Grove Sands range in elevation from about sea level to about 800 feet (244 m) in the Tea Tree Gully area.

On the southwestern side of the Adelaide Embayment, the C.R. Thompson bore No. 75 (Miles, 1952) penetrated a possible paralic sequence of grey sands, micaceous at the base, interbedded with arenaceous and pebbly lignites, 215 feet (66 m) thick, between 190 and 395 feet (55 and 123 m). Foraminifera listed by Crespin (1954) from nearby bores and additional subsurface information (Wade, pers. comm.) applied to structural trends of Oligocene and Miocene sediments, north of this bore suggests that the paralic sequence is older than marine Miocene sediments to the north.

Immediately east of Gawler the unnamed fluvial sediments transitionally underlying shoreline sediments are tentatively correlated with the Oligocene or possibly Lower Miocene sediments in the subsurface. South of Gawler, along the structural axis of the embayment which trends from the Croydon bore to the Elizabeth bore, the paralic sediments may be equivalent to fluvial sediments in the subsurface at Gawler township (Dalgarno, 1961). In the Hallions bore west of Two Wells the sediments become more paralic in the Upper Eocene (Chart 6). The Grange and Croydon bores, near the structural axis on the southwestern part of the embayment show continuous marine deposition during paralic and fluvial phases on the sides of the embayment.

Palaeocurrent data

The palaeogeographic distribution of the Bakers Gully Sands in the Willunga Embayment suggests stream transport from the northeast and east. Streams cut into the staurolite-grade metamorphic basement east of Meadows (Text Fig. 10). Grain size of constituents generally becomes coarser towards the source area.

On the northeast margin of the Adelaide Embayment in the Highbury -Tea Tree Gully area, evidence from channel and cross-strata observations indicate south to southwest stream transport. Although the Golden Grove Sands are folded on the eastern margin of the embayment, a small structural depression adjacent and just west of the Eden Fault is indicated by pebble conglomerates found at the base of the formation within structural lows. The north-south trend of these conglomerates further substantiates the current data. Staurolite-grade basement is situated in and around northern parts of the Barossa Valley. Although the Mid-Tertiary Rolands Flat Sands represent deposition at a different time, Dalgarno (1961) has shown by current and mineralogical data that the Rolands Flat Sands were derived from north of the valley. The palaeogeographical distribution of marine to fluvial sediments in the embayments indicates a low land mass to the south of the Willunga Embayment, and peninsulas of low relief separating the Willunga, Noarlunga, Adelaide and Adelaide Plains Embayments respectively. Small streams probably delivered some sediment to the embayments from those land areas because the major streams from the east and northeast would tend to flow towards lows in the embayments which were in part occupied by the sea. Also the distribution of general grain size, fining-upwards and towards the structural axis of the embayments suggest flood basins or tectonic valley-fills. The low relief of the land mass is further substantiated if one compares the Pleistocene fluvial fans adjacent to fault and fault-line scarps on the southern or eastern margins of the Willunga and Adelaide Embayments. These typical pebble to boulder conglomerates interbedded with coarse sands are much coarser grained than the Upper Eocene to Miocene fluviatile sediments on the southern and eastern margins of the embayments.

From the eastern margins of the embayments to the Upland Areas the deposition of fluviatile sediments over basement becomes younger from Upper Eocene to Mid-Tertiary, respectively. In the southwestern portions of the Adelaide Plains and possible the Adelaide Embayments marine deposition was continuous whereas the Willunga and Noarlunga Embayments were more marginal with intercalation of the lagoonal Chinamans Gully Beds. The probability that the Chinamans Gully Beds laterally grade to marine sediments under the Gulf is emphasized by the thinning of the fluviatile sequence seaward and an increase in marine influence towards the structural axis of the embayment where subsidence of the basement floor was greater than the remainder of the embayment. The Chinamans Gully Beds both genetically and physically are more similar to fluvial sediments than marine sediments and may be considered a tongue of the Bakers Gully Sands.

Western Area

In the western area, the Muloowurtie Formation documents the first Upper Eocene marine ingression to the northern parts of Yorke Peninsula. This formation is only exposed in coastal areas on the eastern side of Yorke Peninsula. At Troubridge Shoal (Map 1) marine sediments which are time-equivalents of the Muloowurtie Formation are present in the subsurface (Chart 4).

At Kingscote on Kangaroo Island about 50 feet (15 m) of Upper Eocene bryozoal limestones are exposed at the coast. These rocks are approximate time-equivalents of the Muloowurtie Formation on Yorke Peninsula. They are fairly coarse-grained and sparite often fills available voids between biogenic constituents. Cross-stratified biogenic limestones are fairly common. The echinoid Australanthus longianus is present within the limestones at Kingscote and the Tortachilla Limestone on the eastern side of the basin (Glaessner and Wade, 1958); it is not known from exposures of the Muloowurtie Formation. Marine sediments of Oligocene and Miocene age are not known from Kangaroo Island.

The Muloowurtie Formation is followed by the lagoonal Throoka Silts (p. 132) which at present are only known in the northern parts of Yorke Peninsula.

The marine Rogue Formation which overlies the Throoka Silts in the northern area is also exposed in southern areas along the east coast of Yorke Peninsula. The Port Vincent Limestone overlies the Rogue Formation, and several remnants of similar limestone are present in many parts of Yorke Peninsula where they overlie basement. The discussion begins with the Muloowurtie Formation.

Muloowurtie Formation

Definition

Tepper (1879) applied the name 'Muloowurtie Clays' to a marine sequence between Rogue and Muloowurtie Points of (in ascending order) fossiliferous, ochre yellow clay with oysters, echinoderms, pelecypods and fish teeth; white plastic clay; one inch of arenaceous limestone with Fibularia gregata Tate ; 9 to 20 feet (3 to 6 m) of unfossiliferous ochreous clays. The 'Muloowurtie Clays' actually consist of biogenic calcarenites, quartz sands, calcareous and glauconitic quartz sands and sandstones and minor thin conglomerates, silts and clays. Because the 'Muloowurtie Clays' contain several non-clayey rock-types, the name Muloowurtie Formation is preferable. As used here, it is restricted to sediments below the 'unfossiliferous, ochreous clays'. The 'unfossiliferous ochreous clays' are assigned to the lagoonal Throoka Silts which disconformably overlie the Muloowurtie Formation.

Type Section

The type section of the Muloowurtie Formation is located at Sliding Rocks (Sect. 3, Chart 3A). The formation as restricted is about 40 feet (12 m) thick and unconformably overlies the Lower Cambrian Kulpara Limestone (or Ardrossan Marble of Tepper). Pale yellowish grey and green glauconitic quartz sands containing thin lenses of pebbles are found in the lower 7 feet (2 m) of the formation. Subround to subangular pebbles of quartz, quartzite, limestone and arkosic sandstone within the sands were probably derived from local source areas. Limestones and arkosic sandstones are common in nearby Cambrian basement. Quartz and quartzitic pebbles predominate and suggest recycling of pre-existing Lower Tertiary fluviatile sediments and/or pebbles from Cambrian conglomerates. The sands are moderately-sorted and medium- to coarse-grained. Glauconite in the form of pellets and internal moulds of foraminifera rarely exceeds 10 % of the bulk composition. The glauconitic sands were not recorded by Tepper, but are here included in the definition of the Muloowurtie Formation.

Richly fossiliferous sands containing a few quartz pebbles overlie the glauconitic sands with gradational contact. The following fossils were recognized: the echinoids Fibularia gregata Tate, Salenia tertiara Tate, Eupatagus, crinoid plates, brachiopods, lamellibranchs, the bryozoans Retepora and Cellepora, ostracods and foraminifera. Lamellibranch shells and bryozoans are usually fragmented. The fossiliferous sands vertically grade to calcareous, silty to fine, quartz sands. The quartz grains fine upwards from the coarser sands below. They decrease as carbonate constituents increase upwards and the sands grade to silty, biogenic calcarenites. The carbonate constituents consist of numerous foraminifera, small shells and fragments, and common echinoid spines. The clay and silt fraction of the carbonates varies between 10 and 20 percent.

Megafossils are similar to those near the base of the formation but are less frequent. The sediments contain lenticular laminae and very thin beds. Ripple-marks and burrows occasionally occur within the sequence. These sediments are the fossiliferous, ochre-yellow clay and white plastic clay of Tepper. They are about 18 feet (5 m) thick and often are speckled buff by iron-oxide staining.

The calcarenites in turn vertically grade to buff speckled, yellowish grey, calcareous very fine to medium quartz sands often argillaceous and silty. They are overlain by resistant, calcareous, very fine to fine quartz sandstones which are very finely-bedded to thin-bedded. The sandstones contain an interbed of pale greenish grey and buff silt. The upper 3 feet (91 cm) of the formation consists of variegated, argillaceous, quartz sands interbedded with arenaceous clays. The uppermost bed of pale greenish grey and pink argillaceous sand shows a rapid increase in grain size upwards from very fine to very coarse quartz grains with granules of quartz and occasional laterite fragments. The sediments above the calcarenites probably constitute the arenaceous, yellow clay and sandrock of Tepper. They are about 15 feet (4 m) thick.

Distribution and lithology

For about ½ mile (0.8 km) north of Sliding Rocks only minor facies variations are found within the Muloowurtie Formation as it gradually dips below sea level (Chart 3A). At Sliding Rocks the basal glauconitic and richly fossiliferous sands thin to a depositional edge on the Cambrian Kulpara Limestone. The finely-bedded calcareous sands which overlie the basal sands in part also thin to a depositional edge as they gradually cover basement.

Just south of Sliding Rocks a second glauconitic quartz sand is found near the middle of the Muloowurtie Formation. It increases in thickness to the south (Sect. 4, Chart 3A) and forms an extension of the Quartoo Sands, a member of the Muloowurtie Formation (p.127). The sand tongue divides the Muloowurtie Formation into lower beds A and upper beds B (informal units) which can be recognized at section 3 and further north (Chart 3A).

The Muloowurtie Formation dips below sea level on the north side of Muloowurtie Point but reappears to the south in coastal cliffs and is traced almost to section 6 where calcareous sands and arenaceous calcarenites of the lower beds thin to a depositional edge on Precambrian crystalline basement. Because the topography of basement is irregular, they exhibit minor facies changes in the vicinity of a hollow located at sections 6 and 7 (Chart 3A). At a lower level in the hollow (Sect. 7) glauconitic and richly fossiliferous quartz sands are similar to those near the base of the type section. Calcareous sands and arenaceous calcarenites above these show vertical grain size trends similar to those in the sequence to the north. At slightly higher levels on the hollow (Sect. 6) a thin sandstone with small to large pebbles of quartz, quartzite and granite gneiss is found on an irregular erosion surface. It contains occasional brachiopods and numerous oysters. On nearby basement an oyster was found in growth position. The fossiliferous sandstone is separated from glauconitic and richly fossiliferous sands by calcareous sands and arenaceous calcarenites filling in the hollow. This suggests that the basal glauconitic and richly fossiliferous sands and the fossiliferous sandstone were probably deposited at about the same time on submarine, low dipping surfaces located at different levels. Oysters flourished in a higher energy environment on the higher surface.

In the vicinity of Harts Mine the thickness of the lower beds is about 10 feet (3 m). A basal transgressive reddish grey conglomerate with quartz, quartzite and granite gneiss pebbles overlies Precambrian basement (Sect. 8, Chart 3A). On the wave-cut platform it is ferruginized and overlies Cambrian arkoses. It contains only occasional, worn lamellibranch fragments in the cliff section, but contains numerous fossils on the wave-cut platform. At section 8 pale and dark yellowish grey moderately-to poorly-sorted fine and medium quartz sands with occasional fossils overlie the basal conglomerate. They are overlain by one foot (30 cm) of resistant, grey-white, very calcareous, coarse to very coarse, quartz sandstone with granules. The basal transgressive conglomerate is stratigraphically controlled by an overall rise of basement beginning about 100 yards (92 m) south of Harts Mine (Chart 3A). This partly explains the thinning of the overlying yellowish grey, quartz sands to less than 4 feet (1 m) in a southerly direction. The sands also thin by lateral gradation to coarser sands of the Quartoo Sand Member. The boundary between the lower beds and the Quartoo Sands is arbitrarily drawn on Chart 3A.

At Rocky Point about 15 feet (4 m) of laminated and thin-bedded calcareous sands and biogenic calcarenites overlie a thin basal conglomerate (Sect. 13, Chart 3A). They show vertical grain size trends similar to lower beds A in northern areas. About ½ mile (0.8 km) south of Rocky Point they dip below sea level. To the north the sediments mostly thin to a depositional edge on Cambrian arkoses and conglomerates. The upper few feet laterally grade to coarse sands and conglomerates, and again the boundary of this part of the Muloowurtie Formation and the Quartoo Sands is arbitrarily drawn on Chart 3A. The depositional thinning of the lower parts of the formation north of Rocky Point and south of Harts Mine accompanied with an increase in quartz constituents and proportionate decrease in carbonate show a depositional high between these two areas (Chart 3A).

Considering upper beds B, south from sections 3 to 6: very fine calcareous quartz sandstones and sands laterally grade to lenticular sands, arenaceous calcarenites and arenaceous silty clays (Chart 3A). In general, these sediments become coarser grained to the south. At section 8 a resistant calcareous medium quartz sandstone near the base of the upper beds is overlain by an arenaceous calcarenite which laterally grades to coarse quartz sands in a southerly direction. Thin beds of greenish grey sands are interbedded with dark yellowish grey, argillaceous, medium quartz sands which overlie the calcarenite of the upper beds at section 8. They are considered thin extensions of the Quartoo Sands.

Although clay minerals are subordinate to quartz and carbonate constituents in the Muloowurtie Formation, montmorillonite and glauconite are common with variable amounts of halloysite and traces of chlorite and illite. Traces of the zeolite clinoptilolite are also present within the formation.

Currents and/or wave-action of water tended to even the topography of the submarine floor by transport of sediment to levels of lower energy during subsidence. Prior to the deposition of the Quartoo Sands and upper beds B most of the irregular topography was filled by lower beds A and counterparts south of the depositional high (Chart 3A).

Quartoo Sand Member

Definition. The name Quartoo Sand Member is applied to variegated pale to dark green, buff, pale grey and red, quartz sands which constitute the upper half of the Muloowurtie Formation in the vicinity of Pine and Rocky Points (Chart 3A).

The type section (13) is located at Quartoo Point (now called Rocky Point). Here, 10 feet (3 m) of quartz sands grade from very fine sands at base to coarse and very coarse sands with granules near the top of the sequence. They are fairly well-sorted with a deficiency in clay and silt grades. The member forms a less resistant unit with bands of goethite staining near base and red iron oxides at upper levels.

Distribution and lithology

From its type section the Quartoo Sand Member extends northwards to the vicinity of section 9 and gradually becomes coarser grained (Chart 3A). Medium to very coarse quartz sands with granules and occasional pebbles are predominant. The sands are thin- to thick-bedded in contrast to finer bedding in other parts of the Muloowurtie Formation. The Quartoo Sands first overlie yellowish grey calcareous sands in the lower part of the Muloowurtie Formation with gradational contact, then to the north extend onto basement rocks near section 12. Between sections 9 and 10 the thickness of the member is mostly controlled by erosional irregularities of basement. A maximum thickness of 21 feet (6.4 m) is found at section 12. Patches of thin basal conglomerates either are confined to small erosional hollows or lie on low dipping erosional surfaces.

Although erosion has removed the Quartoo Sand Member between section 9 and 10, pale grey and green calcareous fine to coarse quartz sands with granules mostly intertongue and laterally grade to other parts of the Muloowurtie Formation in the vicinity of Harts Mine and further north towards Sliding Rocks (Chart 3A). From just south of Harts Mine through Rocky Point the absence of upper beds B could be explained by erosion prior to the deposition of the Throoka Silts, but thin green quartz sands interbedded with the upper beds in the HartsMine area suggest that the main reason for their absence further south is lateral gradation to the Quartoo Sands. From Harts Mine through section 3 at Sliding Rocks a thin, one foot (30 cm), greenish-grey quartzose sand extension of the Quartoo Sands constitutes the uppermost bed of the Muloowurtie Formation (Chart 3A). It is poorly fossiliferous and contains only occasional foraminifera.

An upward increase in grain size is a characteristic textural feature of the Quartoo Sands and its lateral extensions. They are considered regressive, marine sands. Patches of thin conglomerates overlying basement between sections 8 and 10 on the depositional high show the only departure from the coarsening upwards trend. Here quartz sands fine upwards for a few feet above the conglomerates then show the coarsening upwards trend. The conglomerates were probably deposited during the initial ingression of the Upper Eocene sea. Regression is further substantiated between Harts

Mine and Sliding Rocks by the stratigraphic distribution of the glauconitic sand tongue separating lower beds A and upper beds B. The sands of the tongue gradually grade northwards to buff speckled yellowish grey, calcareous, fine, quartz sands near the top of the lower beds. This relationship can be seen just north of Muloowurtie Point where large sigmoidal ripples are found within a thin gradational unit separating the lower beds and the glauconitic sand tongue . The ripples consist of laminated, calcareous, fine quartz sands enclosing coarser sands in the ripple troughs. The fine sands also overlie concave lenses of coarser sands on a basal substrata of laminated and very thinly bedded, calcareous, fine sands. The ripples laterally grade to laminated and very thinly bedded, fine sands to the north. The vertical gradation of biogenic calcarenites to calcareous quartz sands near the top of the lower beds and its counterpart south of the depositional high also suggest regression.

From Harts Mine to just south of Sliding Rocks the glauconitic sand tongue near the middle of the Muloowurtie Formation becomes moderate- to poorly-sorted with a general decrease in grain size, greener in colour with an increase in glauconite, and more fossiliferous with Fibularia gregata, echinoid spines, lamellibranch fragments and foraminifera. As shown by better sorting within the Quartoo Sands and the rare preservation of fossil fragments and glauconite pellets, they were deposited under higher energy conditions over the pre-existing depositional high then extending south past Rocky Point. The deposition of upper beds B north of the depositional high indicates a return to slightly lower energy conditions before the final regression near the top of the formation.

Throoka Silts

Definition and distribution

The name Throoka Silts (from Throoka Creek, Hd. of Muloowurie) is applied to a thin sequence of silts and quartz sands which are the 'unfossiliferous ochreous clays' Tepper recognized between Rogue and Muloowurtie Points. The type section is located at section 4 between Sliding Rocks and Muloowurtie Point (Chart 3A). The formation is easily recognized by its pale colour streaked with thin bands of goethite iron-staining often parallel with bedding, and Liesegang rings. Except for minor gaps it is traceable in coastal cliffs between Rogue and Black Points (Chart 3A). The thickness of the formation varies between 8 and 12 feet (2.3 and 3.6 m). Disconformities separate the lagoonal Throoka Silts from the underlying Upper Eocene Muloowurtie Formation, and the underlying marine, Rogue Formation. These surfaces indicate only small hiatuses.

Lithology

At the type section (4) the Throoka Silts consist of laminated to very thinly bedded quartz sands and subordinate silty and arenaceous clays. No overall vertical or lateral textural trends are apparent. Muscovite is a common accessory mineral and kaolinite is the dominant clay mineral. There are also traces of illite and chlorite.

Over the most southerly mile of outcrop lenticular beds of laminated white and brown arenaceous clays are intercalated within very fine and medium quartz sands and silts. At Rocky Point a 3.5 foot (1 m) cross-stratified siliceous medium quartz sandstone containing silicified wood (Howchin, 1918; Glaessner and Wade, 1958; Crawford, 1965) underlies these sediments. Plant impressions are found on weathered bedding planes. The sandstone contains numerous small scale, planar (with subordinate trough) cross-strata. Both the upper and lower surfaces show irregular and rounded mound-like structures probably formed by differential migration of silica. Bedding cannot be traced through the sandstone to adjacent sands and its shape forms a small lentil. This lentil of sandstone only occurs locally and here is included within the Throoka Silts. Howchin (1918) noted "a similar sandstone located ¾ mile (1.2 km) north of Muloowurtie Point at a small headland". The second siliceous sandstone is found near the base of the overlying, marine, Rogue Formation.

Burrows are fairly rare in the Throoka Silts except near the top of the formation which is overlain by marine sands of the Rogue Formation. The Throoka Silts are not unfossiliferous as described by Tepper but contain large foraminiferal tests (Ammodiscus sp.) which are commonly recognizable in outcrop. Other arenaceous foraminifera and rare Miliolids also are present.

Inland and Subsurface Distribution of the Muloowurtie Formation and Throoka Silts

The Muloowurtie Formation and the overlying Throoka Silts can be seen for only a short distance inland along a few intermittent streams. A road-cut located ¼ mile (0.4 km) west of Muloowurtie Point contains the upper part of the Muloowurtie Formation, the Throoka Silts and part of the overlying Rogue Formation. The Muloowurtie Formation consists of quartz sands that are similar to those of the Quartoo Sand Member. About ½ to 1 mile (0.8 to 1.6 km) inland between Muloowurtie Point and Ardrossan remnants of the Rogue Formation unconformably overlie basement on hill tops about 200 to 250 feet (61 to 76 m) above sea level. Although erosion has removed parts of the formations and no published subsurface data are available, a section normal to the coastline would probably show facies relationships and depositional thinning similar to those within the Muloowurtie formation between Sliding Rocks and the basement high south of Harts Mine (Chart 3A).

The maximum known thickness of the Muloowurtie Formation is 230 feet (70 m) in the Black Point bore (Chart 4). Here at 510 feet (155 m) the formation overlies fluviatile conglomerates mostly consisting of quartz granules. The basal 83 feet (25 m) of the formation consists of pale grey and yellowish grey, moderately-sorted, medium and coarse, quartz sands with a thin 4 foot (1.2 m) glauconitic quartz sand located 13 feet (4 m) from the top of this sequence. The sands are poorly fossiliferous at lower levels with only occasional foraminifera, barnacles and shell fragments, whereas near the top of this sequence foraminifera, echinoid plates and spines and lamellibranch fragments are fairly common. The basal sands are overlain by pale brown, biogenic calcarenites with some interbeds of dark and pale brownish grey, calcareous clays and calcareous quartz sands. The calcarenites contain carbonate constituents similar to those in the coastal sequence. Sponge spicules are fairly common within the clays. Near the top of the formation the calcarenites become arenaceous and are overlain by calcareous, moderately-sorted, medium, quartz sands. In the upper 10 feet (3 m) of the formation well-sorted medium and coarse quartz sands occur at the same stratigraphic level as the regressive Quartoo Sands at Rocky Point. Between 250 and 260 feet (76 and 79 m) a black lignitic sand and lignite overlies the Muloowurtie Formation. It is about time-equivalent to the Throoka Silts in the coastal sequence and was probably deposited in a marginal swamp.

Although differential movements contemporaneous with deposition account for some of the thickness variation in the Muloowurtie Formation between the coastal sequence and the Black Point bore, the abnormal thickness of the formation in the bore is here attributed mainly to a differential relief caused by faulting prior to the deposition of the Muloowurtie Formation. This is documented by marine sediments of the Muloowurtie Formation separating the fluviatile sediments below 510 feet (155 m) in the bore from an erosional remnant of fluviatile conglomerates located just south of section 9 (Chart 3A) and from those located about 200 feet (61 m) above sea level to the north towards Clinton. At least the lower 140 feet (43 m) of the Muloowurtie Formation in the bore is of lowermost Upper Eocene age whereas the surface exposures also of Upper Eocene age are slightly younger (Chapter 3). The faulting probably indicates a rejuvenation of movement along an ancient north-south fault zone located in Cambrian and Precambrian rocks (Chapter 5).

In the Troubridge bore the lower 160 feet (49 m) of the Tertiary sequence consists of calcarenites, clays and quartz sands. On the basis of foraminifera (p.192), it is time equivalent to the Muloowurtie Formation of Upper Eocene age in the Black Point bore (Chart 4). Permian basement in the Troubridge bore is overlain by 100 feet (30 m) of grey-white, fine to medium, biogenic calcarenites with occasional grey, calcareous clays and a basal, yellowish grey, quartz sand. The calcarenites contain bryozoan and shell fragments and foraminifera which are slightly recrystallized. The calcarenite sequence is overlain by 40 feet (12 m) of pale brown and grey, arenaceous, calcareous clays. The clays contain numerous glauconite pellets and internal moulds of foraminifera at lower levels. Pale brown argillaceous fine biogenic calcarenites, 20 feet (6 m) thick, overlie the clays. Both the clays and argillaceous calcarenites contain well preserved foraminifera with occasional sponge spicules and <u>Turritella aldingae</u>. They constitute the lower part of a clay sequence. The description of rock-stratigraphic units is hindered by the absence of subsurface data from areas of possible occurrence between Troubridge Shoal and Black Point (Chart 4).

Between 670 and 690 feet (201 and 219 m) in the Troubridge bore, dark brown silty clays contain some lignitic fragments, occasional foraminifera and glauconitic pellets. They are dominantly marine but occur at about the same stratigraphic level as the Throoka Silts.

Neither the Muloowurtie Formation nor the Throoka Silts are exposed in coastal cliffs between Black Point and Edithburgh. For about 1½ miles (2.4 km) north of Port Vincent and in the subsurface further south, the Rogue Formation unconformably overlies Permian basement. Although erosion by the second transgression that is documented by the lower part of the Rogue Formation could explain the absence of the Muloowurtie Formation and Throoka Silts in this area, the sediments probably thinned to a depositional edge south of Black Point and seaward of the present coastline (Chart 4). The absence of derived calcareous material such as lowermost Upper Eocene foraminifera reworked into the Rogue Formation tends to suggest mainly depositional thinning. It is difficult to imagine an irregular topography persisting in such poorly indurated sediments as the Permian, throughout the Mesozoic and early Tertiary. A north-south ancient active fault Zone (Map 1) is envisaged during the deposition of earliest Upper Eocene marine sediments. This fault Zone determined the boundary between more and less subsiding areas of deposition. This explains the abnormal thickness of earliest Upper Eocene sediments under the western portion of the St. Vincent Gulf.

Rogue Formation

Definition

The name Rogue Formation (from Rogue Point, Hd. of Muloowurtie) is applied to a mainly marine sequence consisting of quartz sands, sandstones and siliceous sandstones, siliceous and arenaceous limestones, mudstones and clays. Sands and sandstones are more common than other rock-types. Tepper (1879) called sediments between Rogue and Muloowurtie Points at lower levels in the formation the '*Turritella* Grits'. Because the formation is characterized by numerous facies changes and erosion which limits its distribution, a composite type section is designated in coastal cliffs from Rogue Point to just south of Muloowurtie Point (Chart 3A).

Distribution and lithology

The Rogue Formation is exposed at low tide at Ardrossan and extends intermittently in coastal cliffs from Rogue Point to 4½ miles (7.2 km) south of Port Vincent (Charts 3A, B; C). It disconformably overlies the Throoka Silts in the northern area and unconformably overlies Permian basement directly north of Port Vincent. About ½ to 1 mile (0.8 to 1.6 km) west of the coastline and extending northwards from Throoka Creek to 1½ miles (2.4 km) northeast of Clinton (Map 1), remnants of fossiliferous siliceous sandstones interbedded with sands overlie basement on low-lying hills (Tepper, 1879; Howchin, 1918; Crawford, 1965). Tepper (1879) and Howchin (1918) correlated these rocks with siliceous sandstones just south of Rogue Point which here are considered part of the Rogue Formation. Directly south of Muloowurtie Point the Rogue Formation is unconformably overlain by the Port Vincent Limestone. In the coastal cliffs south of Black Point the two formations are conformable.

Between Rogue and Muloowurtie Points part of the Rogue Formation consists of either thin-bedded, grey and grey-white, calcareous, siliceous quartz sandstones or arenaceous and argillaceous limestones with minor interbeds of brown and green arenaceous and silty clays. These rocks constitute a carbonate-siliceous facies. The carbonate-siliceous facies contains a fauna of numerous _Turritella aldingae_, sponge spicules and other fossils. Silica is disseminated in the sandstones and often forms layers and nodules. It has replaced carbonate in some megafossils. Within a few feet or less the rocks within the carbonate-siliceous facies laterally grade to grey-white and variegated slightly calcareous, quartz sands. The sands are thin- to thick-bedded. They vary in grain size from very fine- to medium-grained with occasional coarse beds. There is a decrease in grain size where the sands laterally grade to rocks in the carbonate-siliceous facies. Thin beds rich in _Turritella_ can be traced from the carbonate-siliceous facies into the sands. In some places the sands have been leached of carbonate, but thin beds containing moulds of Turritella are still traceable. The carbonate-siliceous facies frequently forms points whereas the sand facies forms bays. Each occurs at various stratigraphic levels in the formation.

Just north and south of Muloowurtie Point the Rogue Formation forms part of a syncline plunging north of east (Chart 3A). A fault on the north side of Muloowurtie Point accentuates the dips of the Rogue Formation, Throoka Silts and the Muloowurtie Formation. The fault plane is essentially vertical trending 10 degrees on the wave-cut platform. The displacement of the beds, which are slightly downthrown to the east is considered small, a few feet or less. To the south the fault strikes inland and is covered by soil and kunkar. On the flanks of the syncline the composite thickness of the Rogue Formation is about 100 feet (30 m).

Directly north of Muloowurtie Point about 35 feet (11 m) of thin-bedded and massive, variegated, moderately-sorted, medium and coarse, quartz sands with an interbed of calcareous sandstone are found near the base of the Rogue Formation (Sect. 5, Chart 3A). The sands become calcareous and contain occasional arenaceous, glauconitic limestones towards Muloowurtie Point proper. They are overlain by a 3 foot (91 cm) dark green, glauconitic, quartz sand with occasional casts of lamellibranchs, bryozoans and corals.

It is found near the top of coastal cliffs adjacent to the south-east corner of a small bay north of Muloowurtie Point and on the wave-cut platform at Muloowurtie Point. On the southern flank of the syncline pale quartz sands are found at the same stratigraphic level suggesting a facies change at depth near the axis of the syncline.

At Muloowurtie Point the glauconitic sand is overlain by about 50 feet (15 m) of pale grey and grey-white calcareous, very fine to fine, quartz sandstones with some thin, hard limestones (Sect. 5, Chart 3A). The sandstones are thin- to thick-bedded. In some beds organic burrows are filled with glauconite while others contain siliceous nodules and sand-pipes. Only a few mega-fossils are found in these rocks.

Immediately south of Muloowurtie Point (Sect. 5b, Chart 3A) soft yellowish grey, well-sorted, very fine to fine, quartz sands constitute the upper 15 feet (4.5 m) of the Rogue Formation. They contain even and wavy, very thin bedding, faintly visible, small scale, cross-stratifications and occasional symmetrical ripple-marks. Although the areal extent of the outcrop is small, sedimentary structures, lithological criteria and rare fossils suggest a beach environment and/or possibly backshore drifting sands.

Between sections 5b and 6 stratigraphic relationships between the sand facies and carbonate-siliceous facies are similar to those north of Muloowurtie Point in the Rogue Formation (Chart 3A). Near the base of the formation ¾ mile (1.2 km) south of Muloowurtie Point, sandstones have been cemented by secondary iron-oxides. They contain internal moulds of brachiopods and lamellibranchs.

Between Harts Mine and Black Point the lower part of the Rogue Formation consists of variegated grey, red and buff, medium to coarse, quartz sands (Chart 3A). The carbonate-siliceous facies is absent in this area. The sands are very thin- to thinly bedded or often massive. They contain thin lenses of small quartz and quartzite pebbles. At lower levels the bedding is either even or lenticular with occasional ripples. At upper levels weathering has reorganized the sands and bedding features are obliterated. The bedding is not typical of a fluviatile environment but could indicate a marine or beach environment. Occasional moulds of Turritella are found at lower levels in the formation immediately south of Rocky Point. They indicate marine influence although their lateral distribution is not great. A near shore, littoral to sublittoral environment is suggested for these sands. Their distribution is similar to the Quartoo Sand Member of the Muloowurtie Formation. They also indicate a higher energy environment than their fossiliferous counterparts to the north, suggesting rejuvenation of the depositional high from Harts Mine in the north to past Rocky Point in the south (Chart3A).

Between Port Julia jetty and Port Vincent (Chart 3B) a composite thickness of the Rogue Formation ranges between 85 and 105 feet (26 and 32 m). The basal beds of the formation are only exposed for a distance of 1½ miles (2.4 km) north of Port Vincent. Here the lower 35 feet (11 m) of the Formation consist of alternating quartz sands and silty clays. A yellowish grey, massive, medium to coarse sand containing a secondary enrichment of iron-oxides unconformably overlies Permian clays and sands (Sect. 23, Chart 3B). It is followed by the first of two identical greenish brown, laminated to very finely bedded, silty clays. Both contain thin lenses of quartz sand near their base and thin beds of either calcareous sandstones or arenaceous, very fine, biogenic calcarenites near their top. These clays contain numerous Chlamys. A 4 foot (1 m) resistant grey-white calcareous very fine to fine quartz sandstone abruptly overlies the lowermost clay. It is thinly bedded and contains the echinoid Duncaniaster. North of section 23 these beds dip below sea level.

The middle part of the Rogue Formation mostly consists of yellowish grey and grey-white, moderately-sorted, fine to medium, quartz sands and sandstones. They are exposed in coastal cliffs between Port Vincent and Sheoak Flat, further north at the base of section 15 and south of Port Vincent between section 25 and a small creek just south of section 26 (Chart 3B; C). Over this distance the sands and sandstones are about 20 to 25 feet (6 to 8 m) thick. Just north of section 21 (Chart 3B) the uppermost sands laterally grade to calcareous siliceous sandstones which are similar to those in the carbonate-siliceous facies located in the northern area. Between Port Vincent and section 21 (Chart 3B) a resistant calcareous medium to coarse sandstone abruptly overlies the lower part of the Rogue Formation. Numerous low angle planar cross-stratifications within the sands are mostly oriented in a northerly direction (Chart 3B). The sands are mostly massive but contain very thin to thin bedding and occasional ripples. The middle part of the formation is poorly fossiliferous except near the top and base of the sequence where foraminifera become fairly common.

Between Port Julia and Port Vincent the upper part of the Rogue Formation consists mostly of interbedded, poorly-sorted, fine and medium quartz sands and sandstones with variable amounts of carbonate and clay. Richly glauconitic sandstones and mudstones, calcareous claystones, arenaceous limestones and siliceous sandstones are less common. Numerous facies changes take place over short distances and specific rock-types are shown in sections 14 to 24 (Chart 3B; C). The upper part of the formation is more fossiliferous than the middle part. Foraminifera, ostracods, lamellibranchs, gastropods, bryozoans, sponge spicules and sharks' teeth are present. A resistant yellowish grey calcareous and siliceous sandstone 42 feet (13 m) above the base of section 15

(Chart 3B) contains the gastropod Turritella tristira whereas beds below this sandstone contain Turritella aldingae. Variegated poorly-sorted medium quartz sandstones with Chlamys and other fossils oriented along the bedding overlie the middle part of the Rogue Formation with gradational contact. Most of the remaining rock-types in the upper part of the Rogue Formation display very thin to thick bedding. Irregularly lenticular bedding and organic burrows also are present.

At section 15 (Chart 3B) pale green slightly glauconitic quartz sands constituting the uppermost beds of the Rogue Formation laterally grade to calcareous arenaceous claystones in the north and south flanks of a fold. The claystones are overlain with gradational contact by arenaceous, bryozoal calcarenites (Port Vincent Limestone). These can be traced southwards near beach level almost to section 19. Here the Rogue Formation and Port Vincent Limestone have been uplifted along a high angle reverse fault. The claystones in the Rogue Formation again laterally grade to mostly pale green, quartz sands which are located on the upthrown side of this fault. Leaching may be invoked to account for the northerly sands at section 15 but is probably not the explanation of sands underlying bryozoal calcarenites at section 19. The change to sands on the crests of these small folds seems more likely to indicate mild structural growth contemporaneous with deposition.

From section 21 through section 22 the upper part of the Rogue Formation has been leached of carbonate. Sandstones, sands and clays form a sequence of beds which contain variable amounts of secondary iron-oxides and silica (Sect. 22, Chart 3B). Facies changes between sandstones, argillaceous sandstones and arenaceous clays can be recognized. These rocks are traceable to calcareous counterparts.

The uppermost beds of the Rogue Formation south of Port Vincent consist of grey and buff, medium, quartz sandstones with interbeds of thin brown, green and buff arenaceous mudstones (Sect. 24, Chart 3C). They laterally grade to poorly-sorted, medium, quartz sands with granules near Devils Gully. Further south at section 26 the sands are about 20 feet (6 m) thick. These sands contain patches of green colouring and are less sorted than the underlying grey quartz sands near the middle of the Rogue Formation. They can be traced through a badly weathered area between section 27 and the first small creek just to the north (Chart 3C). Near section 27 the sands laterally grade to calcareous and argillaceous, quartz sandstones and arenaceous limestones which gradually dip below sea level to the south.

Clay minerals in the Rogue Formation are mainly montmorillonite, mixed layered montmorillonite and glauconite with variable amounts of illite. The zeolite clinoptilolite is fairly common in marine sands at the type section and very common in the upper part of the formation south of Black Point.

Many slump-blocks consisting of parts of the Rogue Formation and overlying sands, clays and kunkar are found between Port Vincent and section 23 (Chart 3B). The clays in the lower part of the Rogue Formation, often saturated with water, provided a slippage plane for these blocks.

Age.

At the type area the Rogue Formation is mostly of Upper Eocene age. Beach sands in the upper 15 feet (4.5 m) of the formation may be of either Upper Eocene or Oligocene age. They do not contain a diagnostic microfauna. In the coastal succession south of Black Point, the Rogue Formation is of Upper Eocene and lowermost Oligocene age. The upper 20 to 25 feet (6 to 9 m) of the formation ¼ mile (0.4 km) south of Port Julia (Sect. 15, Chart 3B)and the upper 5 to 10 feet (1.5 to 3 m) just south of Sheoak Flat are of lowermost Oligocene age. In the remaining part of the succession to the south the Upper Eocene-Oligocene boundary is found near the top of the Rogue Formation. The variation in thickness of Oligocene sediments in the Rogue Formation is attributed to the absence of pale green sands and thin, resistant sandstones near the top of the formation just south of Sheoak Flat where the basal beds of the Port Vincent Limestones are exposed at a similar stratigraphic level. This suggests that in the subsurface at Sheoak Flat part of the Rogue Formation laterally grades to the Port Vincent Limestone.

Subsurface and Correlation

In the Black Point bore the lower 45 feet (14 m) of the Rogue Formation consist of alternating brown, moderately- to well-sorted, coarse quartz sands with occasional pebbles, dark grey and grey, silty to very fine quartz sands and arenaceous, silty clays (Chart 4). Occasional glauconite pellets, pyrite, muscovite and lignitic fragments are found in these sediments. They contain a fauna of small foraminifera, ostracods, lamellibranch shells and fragments, sponge spicules and the gastropod *Turritella aldingae*. It is likely that a facies change takes place in the subsurface towards the northeast because quartz sands predominate in the lower part of the formation at Rocky Point. In the bore the alternating sands and clays are found at a stratigraphic level similar to that of sands and clays constituting the lower part of the Rogue Formation near Port Vincent. Further south at the Adelaide Cement Quarry about 30 to 50 feet (9 to 15 m) of quartz sands overlie Permian basement in the subsurface. Thus, the alternating sands and clays to the north probably grade to quartz sands in the subsurface towards the south (Chart 4). In the Troubridge bore marine pale and grey calcareous arenaceous clays between 630 and 670 feet (192 and 204 m) constituting the upper part of the clay facies are correlated with the lower part of the Rogue Formation in other areas.

Mostly grey and dark grey fairly well-sorted medium and coarse quartz sands are found between 180 and 225 feet (55 and 69 m) in the Black Point bore. The sands contain lignitic fragments and occasional marine foraminifera. At higher levels glauconite pellets and occasional Turritella are present. The sands occur at a stratigraphic level similar to those constituting the middle part of the Rogue Formation in coastal cliffs south of Black Point (Charts 3B;4). Further south, grey argillaceous quartz sands and silts between 610 and 630 feet (186 and 192 m) in the Troubridge bore are about time-equivalent to the sands constituting the middle part of the formation in the coastal cliffs (Chart 4). In the coastal cliffs and the Black Point bore these poorly fossiliferous and fairly well-sorted sands indicate a higher energy environment than laminated to finely bedded clays in the lower part of the formation. At upper levels these sands indicate a slightly lower energy environment in the coastal sequence because they here become more fossiliferous and then are gradationally overlain by poorly-sorted, fossiliferous sandstones of Upper Eocene age in the upper part of the formation. The deposition of these sands lasted slightly longer in the Black Point bore and they also correlate with Upper Eocene beds in the upper part of the formation in coastal cliffs to the south. In the bore marine foraminifera of Upper Eocene age are rare below 180 feet (55 m) in the coarse sands whereas foraminifera of Oligocene age are fairly common at 173 feet (53 m) in finer sands. The stratigraphic relationship of the sands in the bore to those in the southerly coastal cliffs suggests regression and probably stillstand followed by a northerly component of transgression. Further south, the Upper Eocene beds in the upper part of the Rogue Formation in the coastal sequence correlate with the lower 20 feet (6 m) of the Port Vincent Limestone in the subsurface at the Adelaide Cement Quarry and the lower 40 feet (12 m) at Troubridge Shoal (Chart 4).

In the Black Point bore the sediments between 180 and 270 feet (55 and 82 m) mostly correlate with the Rogue Formation at its type area. Quartz sands above 180 feet (55 m) in the bore gradually fine upwards until pale yellowish grey calcareous very fine to fine quartz sands constitute the upper 60 feet (18 m) of the formation. These sands correlate with the uppermost part of the Rogue Formation of Oligocene age and part of the Port Vincent Limestone of Oligocene and lowermost Lower Miocene ages in the coastal cliffs south of Black Point and in the Troubridge bore (Chart 4). Although erosion has removed most of the Rogue Formation a short distance inland and subsurface data is unavailable from areas of possible occurrence, it is probable that most of the formation consists of sands and sandstones similar to those both to the north and south.

The maximum known thickness of the Rogue Formation, 170 feet (52 m), is found in the Black Point bore. The formation becomes thinner to the south by lateral gradation to part of the Port Vincent Limestone and by depositional thinning of the lower part of the formation which documents the second ingression of the Upper Eocene sea. At Muloowurtie Point the unconformity at the top of the Rogue Formation suggests that thinning in the north was probably controlled by erosion or non-deposition prior to the deposition of the Port Vincent Limestone.

Clinton Area. The distribution of bores in the Clinton area extends from Clinton for a distance of about 5 miles (8 km) to the north-northwest and for ½ to 1 mile (0.8 to 1.6 km) inland on the east coast of Yorke Peninsula (Map 1). Johnson (1960; 1964) has shown that marine sediments overlying the Clinton Coal Measures are restricted to the southerly part of the area. In a section normal to the coast (Mining Review, 36) marine sediments located between closely spaced bores are here correlated with nearby outcrops of fossiliferous siliceous sandstones which lap onto basement northeast of Clinton. Although these old subsurface samples are unavailable, similar rocks at the surface containing Turritella aldingae, "Gouldia" lamellata (Tate) and "Coraita" latissima (Tate) are considered by Ludbrook (pers. comm.) to be of Upper Eocene age. They are correlated with the Rogue Formation at its type area (p.140). In the northern part of the Clinton area Harris (1966) noted from palynological evidence that a hiatus exists within the Clinton Coal Measures separating fluviatile sediments of Middle to Upper Eocene age from those of Mid-Tertiary age. Non-deposition or erosion explains the absence of the Upper Eocene marine siliceous sediments in this area. Unconformable relationships between the Rogue Formation of mostly Upper Eocene age and the Port Vincent Limestone of lowermost Lower Miocene age near Muloowurtie Point and within the Clinton Coal Measures north of Clinton suggest that there is an angular unconformity on the northwestern side of the basin. A possible unconformity also occurs at a similar stratigraphic level on the northeastern side of the basin(Chart 7) whereas rocks of Oligocene age and possibly uppermost Upper Eocene age are found in other parts of the basin.

Regression near the top of the Muloowurtie Formation and the overlying lagoonal Throoka Silts at their type area may explain the absence of the Muloowurtie Formation in the Clinton area by a facies change or possibly erosion. This must remain tentative because of the absence of subsurface data from areas of possible occurrence between Clinton and the type area of the Muloowurtie Formation.

Port Julia Greensand(Member).

Definition and distribution. The Port Julia Greensand (Member)was formally designated a formation by Crawford (1965).

The name was applied to a thin 1.5 foot (46 cm) glauconitic sandstone which outcrops for about 200 yards (183 m) near the base of coastal cliffs ¼ mile (0. 4 km) south of Port Julia jetty (Sect. 15, Chart 3B). The name Port Julia Greensand was previously informally used by Ludbrook (1963a). The Port Julia Greensand (Member) as used in an expanded sense here (Chart 3B) is of Upper Eocene age and stratigraphically located near the base of a variable sequence of sandstones with occasional carbonates, glauconitic sandstones and mudstones, and calcareous claystones. All these rocks are here considered the upper part of the Rogue Formation. The separation of the Rogue Formation consisting of mostly sands and sandstones from the two distinct rock-stratigraphic units, the underlying Throoka Silts in the northern area and the overlying Port Vincent Limestone, is practical on the east coast of Yorke Peninsula.

Just south of section 15 the Port Julia Greensand laterally grades to less glauconitic quartz sands. A second glauconitic sandstone or mudstone is now present 2 feet (61 cm) higher in the succession. Glauconitic sandstones and mudstones are found at about this stratigraphic level between Port Julia jetty and Port Vincent (Chart 3B). About 18 feet (5 m) above these rocks in the vicinity of section 15, variegated red, green and buff sandstones and mudstones also are partly glauconitic and can be traced intermittently in coastal cliffs. Both to the north in the Black Point bore and to the south of Port Vincent in coastal cliffs the Port Julia Greensand has laterally graded to quartz sands which are found at a similar stratigraphic level. The Port Julia Greensand here is considered a mappable member of the Rogue Formation when expanded to include variegated sands that include the lower glauconitic sandstones and mudstones at the type area.

Hillwood and Steel (1961) have informally applied the name Port Julia Greensand to glauconitic sediments in the subsurface of the Inkerman-Balaklava area on the northeastern side of the basin. It is unlikely that the Port Julia Greensand extends in the subsurface as a continuous unit to the northeastern side of the basin because it laterally grades to quartz sands both north and south of its type area and further the glauconitic sediments in the Inkerman-Balaklava area also show similar gradational relationships to other sediments. Very glauconitic sands, sandstones and mudstones are not uncommon at different stratigraphic levels in other areas of the basin.

Lithology. The Port Julia Greensand varies in composition between a green glauconitic quartz sandstone and an arenaceous glauconitic mudstone. It contains a fauna of numerous lamellibranchs, gastropods, corals, bryozoans and other fossils. Occasional carbonate shells have been replaced by glauconite whereas internal and external moulds of fossils are predominant. Faecal pellets, pellets and internal moulds of foraminifera are common. Occasional opaque minerals are present but constitute less than 0.5% of the bulk composition.

Port Vincent Limestone

Definition, Distribution and Age

The name Port Vincent Limestone is applied to a distinctive rock stratigraphic unit consisting of bryozoal limestones which are exposed intermittently in coastal cliffs from ¼ mile (0.4 km) south of Port Julia to Edithburgh (Charts 3B, C; D). In this area it overlies the Rogue Formation with gradational contact. An angular unconformity separates it from the Upper Pliocene marine sediments. An erosional remnant of bryozoal limestone at Muloowurtie Point is presumably of this formation; it unconformably overlies the Rogue Formation. The type section is located immediately south of Port Vincent at section 14 (Chart 3C).

The maximum thickness of the Port Vincent Limestone is 410 feet (125 m) thick in the Troubridge bore (Chart 4) and was deposited during the uppermost Upper Eocene to Middle Miocene. The formation thins northwestward to about 130 feet (40 m) in bore No. 37 at the Adelaide Cement Quarry. It also thins to the north where only 10 feet (3 m) of bryozoal limestone is exposed ¼ mile south of Port Julia and 20 feet (6 m) in the Black Point bore. In the coastal area the formation is mostly of Oligocene and Lower Miocene age whereas in the Black Point bore it is only of Lower Miocene age. Thinning is explained by the angular unconformity at the top of the formation, lateral gradation to the Rogue Formation and diastems within the formation.

Lithology

The lower 30 feet (9 m) or less of the time-transgressive Port Vincent Limestone is often arenaceous. It contains very fine to fine grains of quartz in the Troubridge bore; coarser grains of quartz are found in the coastal area and near the base of bore No. 35 at the Adelaide Cement Quarry.

Pale grey and grey-white bryozoal calcarenites varying in grain size from fine to very coarse are found in the Troubridge bore. The finer grained calcarenites contain variable amounts of micrite with secondary growths of the sparry cement. Hard, coarser-grained calcarenites located at 500 feet (152 m) and in the upper 150 feet (46 m) of the Formation are moderately-sorted and contain sparry cement composed of crystals 15-50 μ in diameter. The limestones contain rare glauconitic pellets.

From the type section (14) to the vicinity of Giles Point pale grey and dark yellowish grey medium to very coarse bryozoal calcarenites and calcirudites are traceable (Charts 3A, B; C). Although the limestones are mostly massive, they contain some lenticular, thin beds containing numerous *Chlamys* and other fossils oriented along bedding planes. At lower levels grey-white to pale pinkish white, well-sorted, bryozoal calcirudites contain bryozoal fragments ranging in size from 2 to 15 mm.

Pale grey and grey-white bryozoal limestones laterally grade to hard pink, pinkish grey and orange-red calcarenites and calcirudites near the base of coastal cliffs shown on Charts 3C and3D. The hard limestones are usually associated with small faults, folds and fractures. The voids within the limestones are filled with sparry cement. In a few cases the sparite is confined to well-sorted limestone beds that can be traced laterally. It often accentuates small to medium scale, trough and tabular cross-strata. At the northernmost outcrop at Beach Point an erosional surface, considered a local diastem, separates hard pink calcarenites from soft yellowish grey and grey-white calcarenites. The latter contain a few reworked pebbles of pink limestone which indicate an early introduction of cement. On the other hand, the soft limestones gradually become harder and contain sparry cement indicating at least two periods of cementation. Secondary cementation of limestone along fractures is also common.

About 20 feet (6 m) above the base of pale yellowish grey and dark yellowish grey bryozoal calcarenites between section 21 and Sheoak Flat (Chart 3B), thin-bedded limestones contain lamellibranchs and other fossils which are broken and show signs of abrasion. In contrast to these beds there are occasional intercalated lenticular thin beds containing delicate lamellibranchs and bryozoans which show little sign of abrasion. They are also found north of Sheoak Flat at section 20 where they form lenses at the base of the formation. On the downthrown side of a reverse fault north of section 20, blocks of bryozoal calcarenites have been rotated during faulting.

Although bryozoans are the dominant biogenic constituents, foraminifera, echinoids, lamellibranchs, brachiopods and scaphopods are present. The echinoid *Lovenia woodsi* and the lamellibranch *Eotrigonia semiundulata* are found in the bryozoal limestones of uppermost Oligocene and Lower Miocene Age. *Lovenia woodsi* is very common in Lower Miocene yellowish grey bryozoal limestones at Muloowurtie Point; at upper levels in bryozoal limestones just south of Sheoak Flat; in dark yellowish grey resistant limestones forming the upper parts of coastal cliffs intermittently between section 27 and Giles Point; in coastal cliffs at Edithburgh.

Near Muloowurtie Point a thin transgressive sand, maximum thickness 4 feet (1.2 m), occurs at the base of an arenaceous, moderately-sorted, bryozoal calcarenite (Sect. 5b, Chart 3A). They show a discordance of about 2° with the underlying Rogue Formation. The erosional surface is synclinal in form with a maximum dip of 5° on the northern flank and less on the southern flank. The basal sands are coloured buff and pale green, and grade from moderately-sorted fine sands at base to moderately-to poorly-sorted very coarse sands with granules at upper levels. Quartz is the predominant constituent with grains of granite gneiss and arkosic sandstone. These constituents are also found within the overlying coarse calcarenites which contain intercalated thin beds of very fine to fine biogenic calcarenites.

Other Exposures on Yorke Peninsula

Glaessner and Wade (1958), Ludbrook (1963a) and Crawford (1965) have shown or summarized the distribution of bryozoal limestones on Yorke Peninsula. At most localities remnants of bryozoal limestones unconformably overlie pre-Tertiary sediments and basement. Remnants located at Urania and in the subsurface at Minlaton and upper Yorke Valley (Crawford, 1965, Maitland Sheet) suggest that the Port Vincent limestones overlapped at least the upper part of the Rogue Formation onto basement. Slight regression and stillstand near the middle of the formation may indicate mild uplift and possibly slight erosion of the lower part of the formation prior to the major transgression. Remnants located on the west and southern coasts indicate that basement highs were present during deposition of Upper Eocene and possibly lowermost Oligocene Rogue Formation. On the northern part of Yorke Peninsula remnants of uppermost Lower Miocene bryozoal limestones overlie basement in the Melton area at an elevation of 300 to 400 feet (91 to 121 m). These limestones contain *Lepidocyclina* and indicate a later marine transgression.

The bryozoal limestones in the southern part of Yorke Peninsula are hard, pink, red and white calcarenites and calcirudites cemented by sparite. They are often arenaceous at lower levels. Crawford (1965) formally applied the name Port Turton Limestone which was informally used by Ludbrook (1963a) for a remnant of bryozoal calcarenite about 50 feet (15 m) thick on the western coast at Port Turton. On the northern part of Yorke Peninsula the name Melton Limestone, informally used by Ludbrook (1963a), was formally applied by Crawford (op. cit.) to "30 feet of conglomeratic, sandy, bryozoal cross-bedded limestones rich in Lepidocyclina". The limestones at Melton are correlated with hard bryozoal limestones deficient in quartz between 270 and 310 feet (82 and 94 m) in the Troubridge bore. The arenaceous fraction of these limestones and those at Port Hughes contain lithic and crystalline fragments derived from local source areas.

Hard, pale brown, Lithothamnion limestones are located 2 miles (3.2 km) south of Cuncliffe at elevations not greater than 450 feet (136.5 m) above sea level. They occur at about the same level as the Melton Limestone. Lithothamnion, which are characteristic of shallow water, indicate that the sea probably did not cover portions of Yorke Peninsula at greater elevations.

Pliocene and Early Pleistocene Deposits

General Statement

Uplift associated with folding and faulting movements followed the deposition of Miocene sediments. Glaessner (1953b) has shown the significance of this diastrophic break on the eastern side of the basin where pre-Pliocene Tertiary formations in the embayments became more synclinal in form and/or were displaced across major faults. On Yorke Peninsula and Kangaroo Island these formations became gently folded, with minor faults displacing beds a few feet or less.

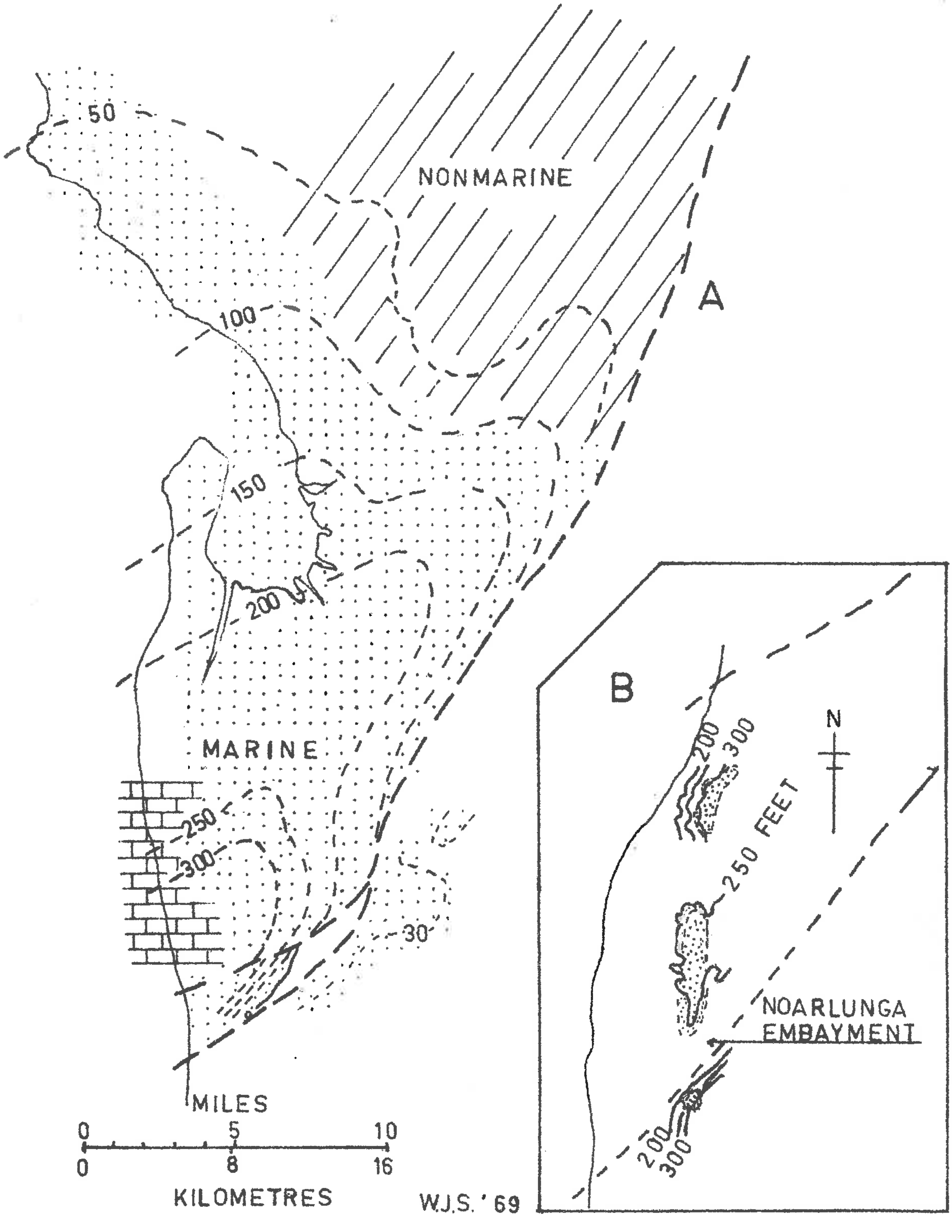
On the eastern side of the basin, modern authors have applied three formational names (Hallett Cove Sandstone, Dry Creek Sands and Seaford Formation) to different rock types which are of Pliocene and/or early Pleistocene age. These rocks are not discussed here on a formational basis alone because local facies changes take place over short distances. The discussion of these rocks begins near the structural axis of the Adelaide Plains Embayment from which Ludbrook (1954-8) monographically described mollusca of Pliocene age found in bore material.

Definition, Lithology and Correlation

The maximum thickness of Pliocene rocks, 220 feet (61 m), is found near the structural axis of the Adelaide Plains Embayment (Text Fig. 11). Between 324 and 550 feet (99 and 168 m) in the Grange bore, grey argillaceous and arenaceous limestones often are slightly glauconitic and contain bryozoal fragments. Thin limestones containing numerous mollusca are interbedded with these rocks. In the Croydon bore a sequence of mainly quartz sands is found between 385 and 605 feet (117 and 184 m). These sands occur at a stratigraphic level similar to the carbonate sequence in the Grange bore, indicating a facies change. Glaessner (1951) applied the name Dry Creek Sands to a fossiliferous quartz sand facies encountered in the Dry Creek bore between 320 and 410 feet (98 and 125 m). This sand facies is found in several other bores east and northeast of the Croydon bore in this embayment. Occasional intervals of quartz sands contain numerous mollusca (Ludbrook, 1954). Lindsay and Shepard (1966) have shown that marine Pliocene sediments probably grade to fluviatile sands and clays towards the northeastern margin of this embayment. The distribution of the carbonate and sand facies is shown in Text Fig. 11.

Text Fig. 11 Isopach and lithofacies map of Adelaide Plains Embayment (A) and contour map (B) of inland Pliocene sediments in Noarlunga Embayment. Heights and depths signified in feet. Stippled area represents outcrop of Pliocene rocks.

TEXT FIG. 11


50
NONMARINE
A
100
150
200
MARINE
250
300
30
MILES
0
5
10
0
8
16
KILOMETRES
W.J.S. '69
B
N
200
300
250 FEET
NOARLUNGA
EMBAYMENT
200
300

Near Redbank a remnant of Pliocene marine rocks is exposed in the bank of the Light River (Ludbrook, 1957a; 1959). This remnant indicates that the Pliocene sea extended further north than the Gawler River.

In the Croydon bore the lower 100 feet (30 m) of Pliocene sediments have been considered a separate rock-stratigraphic unit, the "Croydon Silts", by Rao (1955) and later a "lower silty member" by Steel (1962) and Ludbrook (1963a). Rao and Ludbrook independently consider this unit to be of Lower Pliocene age. Since the "Croydon Silts" are actually very fine to fine quartz sands, they are here considered part of the Dry Creek Sands. These sands of Lower Pliocene age are only found near the structural axis of the Adelaide Plains Embayment. Their presence is attributed to greater subsidence adjacent to the Para Fault, during the initial ingression of the Pliocene sea. In the Croydon bore the overlying richly fossiliferous quartz sands contain the Yatalan fauna of Upper Pliocene age and are correlated with the Dry Creek Sands in the northeasterly parts of this embayment (Ludbrook, 1963a, 1967). These sands are mainly moderately-to poorly-sorted, fine- and medium-grained with occasional granules and small pebbles of quartz and quartzite.

In bores between the Para Fault and the Grange and Croydon bores Steel (1962) and Ludbrook (1963a) recognized another stratigraphic member which consists of fine to medium quartz sands with an assemblage of small mollusca. These sands are about 100 feet (30 m) thick and overlie the Dry Creek Sands. Ludbrook (1963a) considers these sands to be of Pleistocene age. Whether these quartz sands warrant formational status is not significant here.

Several workers have shown the distribution of Upper Pliocene sediments in bores on the northern margin of the Adelaide Embayment. In the vicinity of Adelaide the maximum thickness of these sediments is about 30 feet (9 m). In new excavations at the Adelaide Children's Hospital and the Barr Smith Library Upper Pliocene sediments consist of quartz sands, calcareous quartz sandstones, conglomerates and arenaceous limestones. Thin sands and arenaceous limestones contain numerous oysters including *Ostrea arenicola*, the gastropod *Potamides*, the foraminifer *Marginopora vertebralis* and other fossils.

Ludbrook (1954) and Glaessner and Wade (1958) considered that Pliocene sediments on the upthrown side of the Para Fault (Adelaide area) were mainly characteristic of a shoreline environment. Rao (1955) and these authors considered that Upper Pliocene sediments (Dry Creek Sands) on the downthrown side of the Para Fault were mainly deposited in a shallow water epineritic environment whereas Ludbrook (1954) also considered that the Dry Creek Sands towards the northeastern margin of the Adelaide Plains Embayment were deposited in a shoreline environment. Well-sorted and rounded coarse sands in the upper part of the Upper Pliocene sequence in the Croydon bore also suggest intervals of shoreline conditions.

In the excavation of the Adelaide Children's Hospital thin grey sands and pale green clays abruptly overlie the Upper Pliocene sediments. These sediments contain occasional small mollusca which are typical of the uppermost quartz sand unit (of Pleistocene age) on the downthrown side of the Para Fault. Sediments of either Pliocene or Pleistocene age are unconformably overlain by fluviatile sediments in the Adelaide and Adelaide Plains Embayments.

Crespin (1954) applied the name Hallett Cove Sandstone to a 4 foot (1 m), grey, fossiliferous sandstone located in coastal cliffs just north of Hallett Cove on the structural high separating the Adelaide and

Noarlunga Embayments (Text Fig. 11). The Hallett Cove Sandstone varies in composition from a pale grey, very calcareous, quartz sandstone to an arenaceous limestone. Small foraminifera and subround, fine and medium quartz grains often are present in a carbonate matrix. Moulds of fossils indicate leaching of carbonate. Numerous small to large pebbles of quartz, quartzite and occasionally mica schist are found near the base of this formation where it unconformably overlies Permian basement. These pebbles were probably derived from nearby Permian and Proterozoic basement. Between Hallett Cove and Sellick Beach the distribution of Upper Pliocene rocks has been summarized by Howchin (1923), Crespin (1954) and Glaessner and Wade (1958). These rocks are intermittently exposed in a southerly direction from Hallett Cove to just past O'Sullivan Beach, north of Christies Beach, in the vicinity of Ochre Cove, and adjacent to Maslin and Aldinga Bays. In the coastal sequence these rocks dip below sea level near Snapper Point in the Willunga Embayment and occur at elevations between 80 and 120 feet (25 and 37 m) on structural highs separating the Adelaide, Noarlunga and Willunga Embayments. The outcropping rocks of Upper Pliocene age which include the Hallett Cove Sandstone at its type section are correlated with Upper Pliocene sediments of the Dry Creek Sands in the subsurface of the Adelaide Plains Embayment. These rocks contain numerous oysters and other mollusca, foraminifera including *Marginopora vertebralis*, echinoids, bryozoans, *Lithothamnium*, crab claws and other fossils (Glaessner and Wade, 1958).

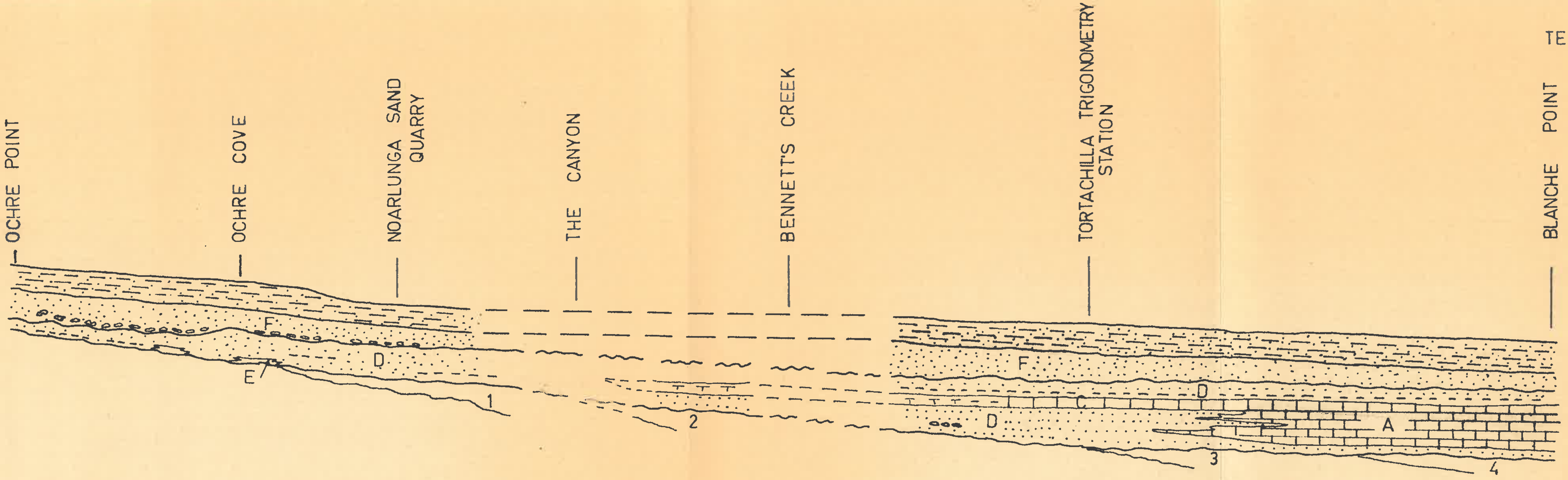
In coastal cliffs near Port Willunga jetty about 20 feet (6 m) of interbedded grey, white and yellow fossiliferous quartz sands, calcareous sandstones, and arenaceous limestones constitute the southernmost 'Pliocene' division described by Reynolds (1953, p. 32). Crespin (1954, p. 14) correlated this sequence of rocks with the Hallett Cove Sandstone. These rocks can be traced in a northerly direction to the north side of Blanche Point. From Blanche Point to 120 yards (110 m) south of the Tortachilla Trigonometric Station carbonate-rich rocks located below the uppermost 4 to 5 foot (1 to 1.2 m) arenaceous limestone intertongue and laterally grade into yellowish grey and buff, quartz sands with lenses of conglomerates and thin beds of green and brown clays (Text Fig. 12). In vertical section these rocks are physically similar to those exposed in excavations on the northern side of the Adelaide Embayment (p. 167). From the Trigonometric Station the

Text Fig. 12 Cross-section of Pliocene and Pleistocene sediments exposed in coastal cliffs adjacent to Maslin Bay. Modified after Reynolds, 1953 and Ward, 1966.

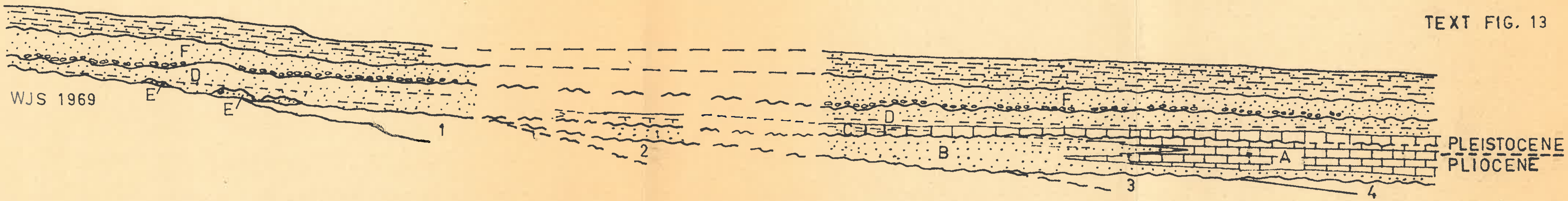
Text Fig. 13 Reinterpretation of Pliocene cross-section showing an unconformity in Pleistocene limestones, A, C and also separating sediments B, C.

A. Marine, arenaceous limestones
B. Beach and littoral, buff and yellowish grey sands with fossiliferous ferruginous pebble lenses
C. Lagoonal, upper fossiliferous limestone
D. Fluvial, Seaford Formation
E. Marine, fossiliferous, ferruginous conglomerates
F. Fluvial, Ochre Cove Formation
1-4 Older Tertiary beds.

TEXT FIG. 12



TEXT FIG. 13



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yellowish grey and buff sands extend further north to just south of the Canyon. Over this distance these sands are thinly bedded and contain ripples and small scale planar cross-strata. Thin lenses of conglomerate and coarse quartz sand contain broken lamellibranch shells. The moderately-to well-sorted fine to medium quartz sands and broken fossils in coarser detritus suggest a high energy environment, probably littoral and beach rather than the terrestrial environment suggested by Reynolds (1953).

Reynolds (1953) considered that mainly fluviatile sands extending further northwards, from the Noarlunga sand quarry to past Ochre Cove, are lateral equivalents to the marine sands and the uppermost limestone between Blanche Point and the Canyon. Ward (1965; 1966) agreed with this stratigraphic interpretation. He applied the name Seaford Formation to the fluviatile sands and the marine sands. He also included within this formation 2 to 16 feet (0.5 to 5 m) of mainly fluviatile sands and clays which overlie the uppermost limestone in the south (Text Fig. 12).

The type section of the Seaford Formation is located at Ochre Cove (Ward, 1966). About 18 feet (5.5 m) of pale yellow and grey quartz sands and argillaceous quartz sands containing thin green and grey clays are exposed here. The green clays weather grey. Lenses of conglomerate consisting of quartz, quartzite and vein quartz pebbles occur in this formation. Further south above the uppermost limestone (Text Fig. 12) the formation still contains these rocks. Thin, lenticular, grey and green clays are usually found near the base of these rocks.

Glaessner and Wade (1958) first recognized that a rock of Pliocene age is exposed in coastal cliffs adjacent to Ochre Cove. This rock is a fossiliferous ferruginous conglomerate which is considered a facies within the Hallett Cove Sandstone by Ward (1966). This conglomerate consists of rounded pebbles of quartz and quartzite in a quartz sand matrix. It contains the foraminifer Marginopora vertebralis and lamellibranch fragments. Both north and south of Ochre Cove on the structural high separating the Willunga and Noarlunga Embayments, several remnants of this conglomerate overlie either basement or a wedge of North Maslin Sand (Text Fig. 12).

Ward (1966, p. 27) indicates that at Ochre Cove "the contact between the formations (Hallett Cove Sandstone and Seaford Formation) is gradational and no break in sedimentation is recognized". Actually this contact is unconformable. The Seaford Formation abruptly overlies the fossiliferous conglomerate (Hallett Cove Sandstone) at Ochre Cove but immediately north and south of this area it drapes over this rock and then overlies basement. In some exposures faint bedding exhibited by sands of the Seaford Formation terminates against remnants of the fossiliferous conglomerate.

Reynolds (1953) indicated that the erosional surface separating Pliocene beds and earlier Tertiary Formations dips in a southerly direction from about 90 feet (27 m) above sea level at the Noarlunga sand quarry to sea level just north of Snapper Point. The dip becomes flatter in the vicinity of the sand quarry and the erosional surface gently rises to about 115 feet (35 m) just north of Ochre Cove. Actually this surface is broadly sigmoidal in section when traced from the axis of this embayment to its northern side. Below the uppermost limestone between Blanche Point and the Canyon the marine sands (shown as partly Seaford Formation by Ward, 1966, Fig. 8) thins from about 15 feet (4.5 m) in the south to 6.5 feet (2 m) in the north. It is likely that erosion is the cause of this thinning. A second unconformity (first recognized by Reynolds, 1953, p. 134) is found between the uppermost limestone and these marine sands (Text Fig. 13). Beds above and below this surface show a gentle angular discordance in a northerly direction. If this erosional surface and the basal erosional surface are projected in a northerly direction across gaps, from north of Blanche Point to the quarry, these surfaces converge just south of the quarry (Text Fig. 13). Further north, the unconformity between the remnants of fossiliferous conglomerate and the Seaford Formation substantiates this stratigraphic relationship. If we return to Blanche Point the second erosional surface is now found between the uppermost limestone and carbonate-rich rocks. This surface can be traced in a southerly direction from Blanche Point to just north of Snapper Point. Over this distance beds above and below this surface are parallel, indicating a disconformable relationship. The uppermost limestone is considered here the lateral equivalent of the Seaford Formation, and unconformably to disconformably overlies the Hallett Cove Sandstone. It thus cannot be regarded as Hallett Cove Sandstone. Thus, also, the marine and shoreline sands below the upper unconformity observed between Blanche Point and the Canyon cannot be regarded as Seaford Formation.

Near Blanche Point the Pliocene to Pleistocene boundary is found in a conformable sequence of rocks. About 4 feet (1 m) of argillaceous limestone below the uppermost limestone laterally grades in a northerly direction to thin, green and brown clays which are very thinly bedded or laminated. According to B. Daily (pers. comm.) this sequence of rocks contains a fauna of small mollusca indicating correlation with sediments of Pleistocene age in the Adelaide Plains Embayment. Ludbrook (pers. comm. to B. Daily) confirmed a Pleistocene age for these rocks by identifying the mollusca *Placamen placidum* (Philippi), *Anapella variabilis* (Tate), *Batillaria* (*Batillariella*) *estuarina* (Tate) and *Diala lauta* Adams. These sediments and mollusca are characteristic of a lagoonal environment. The uppermost limestone contains a similar fauna of mollusca. The erosional surface between this limestone and the underlying beds indicates a small temporal break during the early Pleistocene. The sediments below beds of Pleistocene age and above the basal erosional surface contain the *Yatalan* fauna and are of Upper Pliocene age.

The Seaford Formation extends in a northerly direction from Ochre Cove to just past Hallett Cove. It abruptly overlies the type section of the Hallett Cove Sandstone. To the south, towards Black Cliff, the Seaford Formation contains occasional, lenticular clays which contain a molluscan fauna similar to those in the limestones of Pleistocene age near Blanche Point. Immediately south of Black Cliff the Hallett Cove Sandstone has been eroded prior to the deposition of the Seaford Formation. An erosional surface separates the two formations here and in places the Seaford Formation unconformably overlies basement. Between Hallett Cove and Snapper Point the Seaford Formation is unconformably overlain by fluviatile quartz sandstones and conglomerates which Ward (1965; 1966) calls Ochre Cove Formation.

A remnant of mainly fossiliferous quartz sandstones and arenaceous limestone unconformably overlies basement about one mile (1.6 km) east-southeast of Hallett Cove between 250 and 350 feet (76 and 107 m) above sea level (Text Fig. 11B). These rocks are very fossiliferous at lower elevations on the southerly portion of this remnant. At higher elevations the remnant consists of poorly fossiliferous calcareous conglomerate consisting of quartz, quartzite and claystone pebbles. Just south of this remnant Sprigg (1942), Ward (1965; 1966) and Twidale et al. (1967) have traced remnants of pinkish grey calcareous sandstones in a southerly direction to one mile (1.6 km) northeast of Noarlunga. Over this distance these outcrops are about 250 feet (76 m) above sea level except for the most southerly outcrop which is about 340 feet (104 m) above sea level. The most southerly outcrop of calcareous sandstone contains a well-sorted, medium-grained quartz fraction and high angle (greater than 30°) planar cross-stratifications which probably substantiate a dune environment proposed by Sprigg (1942) and Twidale et al. (1967).

Howchin (1923) first correlated the northernmost of these remnants with rocks now considered of Upper Pliocene age at the coast. Ludbrook (1961) substantiated this correlation because the Hallett Cove Sandstone at its type section and this remnant contained a fauna of Pliocene age (Twidale et al.). Sprigg (1942) considered these remnants to be of Pleistocene age but in a later publication (Sprigg, 1961) also considered them to be of Pliocene age. Although Ward (1968, p. 159) recognized that the northern remnant contains the <u>Yatalan</u> fauna, he informally named these rocks the Patpa beds because "the field relationships show that the beds form a distinct unit in rock stratigraphic terms, and are younger than Hallett Cove Sandstone". Ward considers that the high level beds are of Pleistocene age because the southerly remnants overlie unfossiliferous ferruginous conglomerates and quartz sandstones which have a similar appearance to fluviatile rocks (Ochre Cove Formation) overlying the Seaford Formation in the coastal area. The Seaford Formation as restricted here is considered of Pleistocene age because it partly grades into and partly overlies the uppermost limestone of Pleistocene age in coastal cliffs adjacent Maslin Bay. It is thus more plausible to query the age of the fluviatile rocks underlying the high level rocks of Upper Pliocene age. It has been previously shown in describing the earlier Tertiary section that fluviatile rocks may have a similar appearance while palynological evidence and the stratigraphic relationships between marine and fluviatile rocks indicate different ages. The lateral continuity of these high-level fluviatile rocks with other formations cannot be proved here, so the relative age of these rocks has to be determined by correlation. They overlie unconformably either basement or Blanche Point Marls. If one considers depositional events during the Tertiary the stratigraphic relationships suggest two possible times for the deposition of these fluviatile rocks. Firstly, they could have been deposited in small channels of streams which were emptying into the Pliocene sea, essentially contemporaneously with marine sediments laid down during the initial ingression of the sea. Alternatively, these rocks could be of Upper Eocene age and possible time-equivalent to the Chinamans Gully beds which contain a similar conglomerate and sand facies and overlie the Blanche Point Marls near the mouth of the Onkaparinga River. The first alternative seems likely when one considers that the facies distribution between marine carbonate-rich rocks and littoral sands and conglomerates indicates a landward source of supply of coarser detritus. Further, this interpretation gains merit when the stratigraphic distribution of these rocks is compared with those of earlier formations. For instance, fluviatile deposition continued on the northeastern side of the Willunga Embayment while the lower sediments of the marine Port Willunga beds were being deposited in other parts of the embayment. Eventually, with further ingression of the sea, the fluviatile rocks were covered by marine sediments. The depositional interpretation of these mainly Upper Eocene sediments is analogous to that of the Pliocene rocks if it is considered that at both relevant times dune sediments were being deposited over fluviatile sediments while shallow water and littoral sediments continued to be deposited in other areas.

Between Willunga and Sellick Hill maturely dissected benches are found on the Willunga scarp at 540 and 600 feet (165 and 183 m) above present sea level (Ward, 1965-8). About three miles (4.8 km) northeast of Willunga these benches are covered by fluvial fan deposits. Ward (1965-8) considered that these benches were formed by marine erosion because the geometrical shape of the surfaces is parallel to the coast southwest of Sellick Beach and beach deposits consisting of sands and rounded quartz and quartzite pebbles veneer the lower surface.

Although several workers considered that structural movements continued along the Willunga Fault in the late Tertiary and Quarternary, Ward (1965-8) indicates that significant structural movements on the eastern side of the basin were essentially completed prior to the deposition of Pliocene sediments and that only very mild movements have taken place along the Willunga Fault in the Quarternary. The presence of a 600 foot (183 m) bench on the Willunga scarp then led Ward to believe that the Pliocene sea level was at least 600 feet (183 m) above present sea level. Further he considered that the sea remained here while on the structural highs separating the Adelaide, Noarlunga and Willunga Embayments accordant surfaces were being formed by lateral planation; that the deposition of sediments from rivers in this area forced a hypothetical Pliocene shoreline to retreat towards the west. Since Ward believes that the high level fossiliferous rocks were deposited later than marine rocks of Upper Pliocene age at the coast, he considers that a 370 foot (113 m) bench landward of these rocks was cut partly by a second ingression of a sea. Ward then correlates these shorelines and later shorelines of which four were determined by aggradational and erosional cycles of fluviatile rocks with late Tertiary and Quaternary shorelines in other parts of the world.

Twidale et al. (1967) questioned the 600 foot (183 m) Pliocene sea level because the depth of water would then be over 1000 feet (305 m) in the Adelaide Plains Embayment. Ward (1967) did not deny the shallow water and/or littoral origin of these rocks but considered that ultimately this sea reached the 600 foot (183 m) level. Ward infers then that deeper water sediments were not deposited or that erosion has subsequently removed them.

The basis of Ward's interpretation was that the Seaford Formation interfingered with marine rocks of Upper Pliocene age but as is shown here this formation overlies with angular unconformity rocks of Pliocene and early Pleistocene age (Text Fig. 13). Near Blanche Point conformable rocks of Upper Pliocene and early Pleistocene age below this contact could not have been deposited in 600 feet (183 m) of water. The environmental relationships of these rocks indicates that the ingression and regression of the Pliocene sea was followed by lagoonal deposition during the early Pleistocene. Near the coast on the northern side of the Willunga Embayment, a littoral environment was widespread whereas towards the structural axis of this embayment marine sediments were probably deposited in less than 50 feet (15 m) of water. This depth of water is reasonable because at present the initial depositional surface shows a dip of 30 feet (9 m) per mile (1.6 km) and these sediments are slightly tilted as shown by the second unconformity on the northern margin of this embayment. The high level fossiliferous rocks which are considered by Ward to indicate a second ingressive sea with depths of 370 feet (113 m) were more likely deposited as shoreline and dune environments during the first and only ingression of the Pliocene sea in this area.

If structural movements had essentially ceased along the Willunga Fault as claimed by Ward (1965-8) then marine rocks of Pliocene age should be present about 20 feet (6 m) above sea level ½ mile (0.8 km) south of Sellick Beach. About 6 feet (1.8 m) of interbedded green clays, grey calcareous claystones and argillaceous limestones are exposed here. This sequence of rocks contain thin lenses of quartz sandstones and conglomerates consisting of quartz and quartzite pebbles. Thin lenticular beds of clay and limestone are occasionally laminated or thinly bedded. Occasional root structures are found in these rocks. This sequence of rocks unconformably overlies the bryozoal calcarenite facies of the Port Willunga Beds which form a small anticlinal structure in this area. They are gradationally overlain by argillaceous sandstones which constitute the lower beds of fluvial fan sediments. Although the limestone, clay and conglomerate sequence is considered of Pliocene age by several workers, these rocks contain a poor fauna of nonmarine land snails and the estuarine species Salinator fragilis (Ludbrook, pers. comm.) which are also present in rocks of Pleistocene age near Blanche Point. They are not known from rocks of Upper Pliocene age (Ludbrook, pers. comm.). It is possible that the small anticline was a depositional high while sediments of Pliocene age and possibly Pleistocene age were being deposited in other areas. It is more likely, however, that structural movements in the basement rejuvenated this anticline and that these rocks were stripped prior to the deposition of lagoonal sediments during the early Pleistocene. The lagoonal beds show an apparent dip of 10° on the northern flank of the anticline, while dips of 1° to 2° are found on its southern flank. These dips show that some structural movement has also taken place after they were deposited and suggest the probability of earlier movement. The lower few feet of overlying fluvial beds are covered on the northern flank of this anticline, but Campana and Wilson (1954) have shown that fluvial fan deposits located to the south near the Willunga scarp have been partly tilted and faulted.

The ages of the benches on the Willunga scarp are still in doubt because sediments which occasionally veneer the lower surface are unfossiliferous. It is possible that these benches are of Pliocene age and have been subsequently uplifted to their known height during the Pliocene and Quarternary but they may be related to other Tertiary or Quarternary events. It is unlikely that these benches are older than Miocene because denudation would tend to destroy earlier benches on fault-line scarps.

Ward (1965-8) believes that structural movements on the Clarendon-Ochre Cove Fault had ceased prior to the deposition of the Seaford Formation because this formation can be traced across this fault without a structural break. Although several maps of this area including the Echunga Sheet (Sprigg and Wilson, 1954) show a fault at the coast, it is not exposed in basement rocks. This fault is inferred in basement rocks at depth because pre-Pliocene Tertiary formations have been passively folded over it. The Seaford Formation is partly covered in this area and it is difficult to tell whether this formation also has been folded. Occasional beds show an apparent dip of 7° to the north which may be either structural or depositional. Although structural movements may have ceased prior to the deposition of the Seaford Formation, the unconformity between a remnant of Upper Pliocene fossiliferous conglomerate and the Seaford Formation on the north side of Ochre Point indicates mild structural movements after and probably during the deposition of Upper Pliocene sediments. The high level remnants of Upper Pliocene fossiliferous rocks located one mile (1.6 km) north of Noarlunga show an elevation difference of about 90 feet (27 m) with the higher remnant located on the upthrown side of the inferred Clarendon-Ochre Cove Fault. This elevational difference suggests folding of these rocks by rejuvenation of movement along this fault.

The minimum cumulative structural movement of the pre-Pliocene surface during the late Tertiary and Quaternary between the structural high separating the Noarlunga and Adelaide Embayments and the structural axis of the Adelaide Embayment varies between 200 and 300 feet (61 and 92 m) near the coast (Chart 2).

Sediments of Upper Pliocene age near the structural axis of the Adelaide Plains Embayment, west and north of

Adelaide, contain epineritic shallow water sediments which are thicker than those of a shoreline environment either towards the northwestern side of this embayment or on the upthrown side of the Para Fault in the vicinity of Adelaide (Text Fig. 11). These stratigraphic relationships suggest that the Para Fault determined the boundary between high and slightly subsiding areas with greater subsidence occurring on the downthrown side of this fault. These movements are consistent with earlier movements that were taking place during the deposition of pre-Pliocene Tertiary rocks (Chapter 5). The cumulative displacement of the pre-Pliocene surface across the Para Fault is about 500 feet (153 m) whereas beds of Pleistocene age show a vertical separation of about 300feet (92 m).

Although faulting has taken place after the deposition of marine Pliocene sediments between the Adelaide and Adelaide Plains Embayments, Ward (1966b; 1968) argues that a eustatic change of sea level would show a similar pattern of environments if a fault scarp was present. It becomes important in this case to assess the nature of the pre-Pliocene surface.

The pre-Pliocene surface is remarkable because no sign of relief can be seen between hard and soft rocks. If these rocks did not show abrupt relief even in areas folded and eroded during the Tertiary, it is unlikely that a scarp (Para Fault) which is composed of similar rock-types in the Adelaide area would have survived the erosive interval between lower Middle Miocene and the Pliocene. Glaessner (1953b) indicated that structural highs as well as lows were peneplaned prior to the deposition of Pliocene sediments. This erosional surface probably had acquired a gentle slope towards structural highs which also include the Mt. Lofty Ranges. The nature and pattern of structural movements in the eastern area as well as other areas during the Cainozoic is more fully discussed in Chapter 5.

Crawford (1965) has used the name Hallett Cove Sandstone for fossiliferous sandstones and arenaceous limestones of Pliocene age on Yorke Peninsula. In the Troubridge bore arenaceous limestones of Pliocene age are about 100 feet (30 m) thick whereas on the eastern coast of Yorke Peninsula these rocks rarely exceed 10 feet (3 m). In the coastal area these rocks can be intermittently traced from Edithburgh to just past the vicinity of the Port Vincent golf course. Over this distance the Hallett Cove Sandstone unconformably overlies the Port Vincent Limestone in the south and the Rogue Formation in the north.

Near Giles Point (Chart 3B) arenaceous limestones contain numerous oysters and other fossils (Ludbrook, 1959). These oysters are often oriented parallel to bedding and show contact relationships to one another with medium to coarse-grained quartz sand filling voids. Further north oysters are less numerous but *Marginopora vertebralis* is common with the mollusc *Anodontia sphericula*, other mollusca, and bryozoans.

Between Port Vincent and Sheoak Flat the Hallett Cove Sandstone has been considerably leached of carbonate. Just north of the golf course it is mainly medium to coarse quartz sandstone which contains occasional moulds of fossils. Immediately north of section 20 (Chart 3B) the sandstone becomes very argillaceous and ferruginous with a reticulate red and grey mottling. This mottling results from a later lateritic profile. In coastal cliffs north of Sheoak Flat and on the northern side of the basin marine sediments of Pliocene age are not known. Fluviatile rocks in this area may be partly of Pliocene age but there is no fossil evidence to confirm this.

On Kangaroo Island outcrops of fossiliferous arenaceous limestones located about 8 miles (12.8 km) west of Kingscote are of Pliocene age (Ludbrook, 1959). These limestones contain quartz and quartzite pebbles and occasional laterite fragments.

CHAPTER 3

INTRABASINAL CORRELATIONS

Correlation of Upper Eocene Sediments

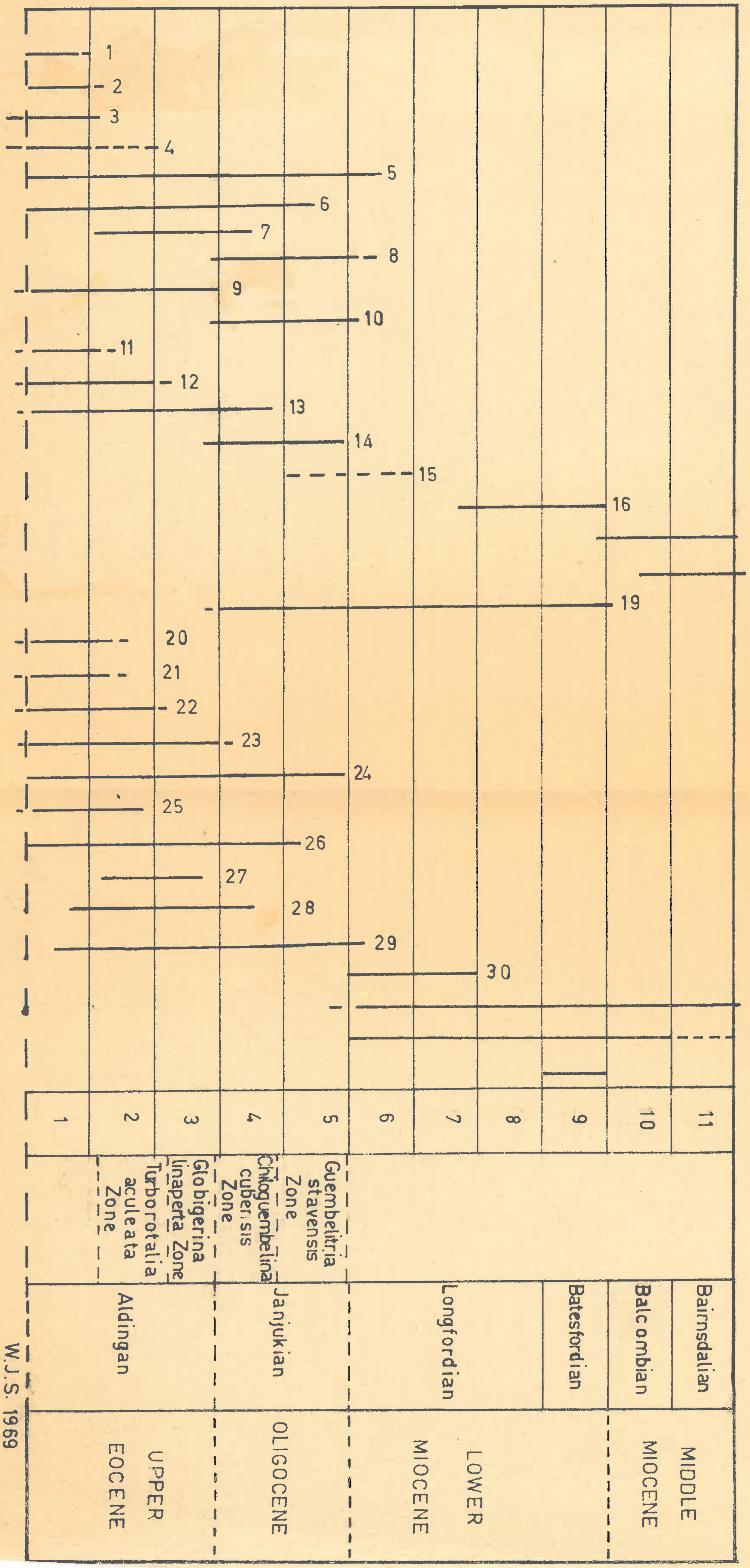
The oldest marine beds in the St. Vincent Basin are considered to be of Upper Eocene age (Glaessner, 1951; Glaessner and Wade, 1958). In the Noarlunga and Willunga Embayments the South Maslin Sands contain only occasional recognizable foraminifera (p.193). The overlying Tortachilla Limestone contains well developed foraminifera of which Glaessner and Wade recorded the planktonics *Globigerapsis index* and *Chiloguembelina rugosa* (=*C. cubensis* vide Lindsay, 1967). They indicated that these planktonics persisted into the overlying Blanche Point Marls where Parr's discovery (see Glaessner, 1951) of *Hantkenina alabamensis* was made in the Transitional Marl Member at Maslin Bay. Ludbrook (1963a) recorded *Globigerina linaperta* Finlay from the Tortachilla Limestone and *Pseudohastigerina micra* (Cole) (=*Globanomalina micra*) from the Transitional Marl Member was recorded by Wade (1964, Fig. 3). *Truncorotaloides collactea* Finlay, *Globorotalia inconspicua aculeata* Jenkins (=*Turborotalia aculeata* vide Lindsay 1967) and probably *Globigerinita* (*Catapsydrax*) *echinatus* (Bolli) also occur within these formations. This foraminiferal assemblage characterizes the *Hantkenina* Zone (Faunal Unit 1 of Carter, 1958), which was first named by Glaessner (1951). Only occasional specimens of

Hantkenina are reported from the Transitional Marl Member at Maslin Bay and from glauconitic quartz sands in the Willunga Embayment (Glaessner and Woodard, 1956). Since the occurrence of *T. collactea* is more widespread in this basin, its final appearance is used for correlation (Text Fig. 14). This foraminifer is also present within the basal beds of the overlying Banded Marl Member at Maslin Bay. In other areas where planktonic foraminifera are more common and better developed, Jenkins (1965, Fig. 2) and Ludbrook (1967, Fig. 2) have shown that the final appearance of *H. alabamensis* is slightly above that of *T. collactea* in New Zealand and Australia.

In the Adelaide Plains Embayment, *T. collactea* is present between 1540 and 1650 feet (469 and 502 m) in the Grange bore (Chart 8). In this bore, planktonic foraminifera associated with *T. collactea* are similar to those recorded in the coastal sequences.

On the western side of the basin, sediments of this age are only known from the subsurface (Chart 8). In the Black Point bore the first occurrence (down the hole) of *T. collactea* is at 390 feet (119 m) while in the Troubridge bore it is found (rarely) between 760 and 850 feet (232 and 259 m). Well developed planktonics associated with *T. collactea* in the Black Point bore are *Globigerapsis index*, *Globigerina linaperta*, *G. angiporoides* (rare), *G. ampliapertura*, *G. officinalis*, *Turborotulia aculeata*, *T. increbescens* (rare), *Globigerinita* cf. *martini martini* Blow and Banner, *Globanomalina micra* (rare) and *Chiloguembelina cubensis*.

Text Fig. 14 Faunal Ranges used for intrabasinal correlations. Modified after Carter, 1958; Wade, 1964 and Lindsay, 1967.



(1) Hantkenina alabamensis
(2) Globanomalina micra
(3) Truncorotaloides collactea
(4) Globigerapis index
(5) Globigerina ouachitaensis
(6) Globigerina officinalis
(7) Globigerina angiporoides
(8) Globigerina euapertura
(9) Globigerina linaperta
(10) Globigerinita unicava
(11) Globigerinita echinatus
(12) Turborotalia inconspicua aculeata
(13) Chiloguembelina cubensis
(14) Guembelitria stavensis
(15) Globigerinoides quadrilobatus primordius
(16) Globigerinoides bisphericus
(17) Globigerinoides glomerosus
(18) Orbulina suturalis
(19) Cassigerinella chipolensis
(20) Pseudopolymorphina sp.
(21) Asterigerina adelaidensis
(22) Maslinella chapmani
(23) Crespinina kingscotensis
(24) Lamarckina cf. airensis
(25) Aragonia sp
(26) Cibicides pseudoconvexus
(27) Bolivinella sp.
(28) Svratkina perlata
(29) Sherbornina atkinsoni
(30) Sherbornina cuneimarginata
(31) Operculina victoriensis
(32) Calcarina verriculata
(33) Lepidocyclina howchini

Faunal Zones (Carter 1958, 1964)

Faunal Zones (Lindsay, 1967)

TEXT FIG. 14

In the Troubridge bore *Globigerapsis index*, *G. officinalis*, *G. ampliapertura*, *G. linaperta* and *Chiloguembelina cubensis* are present.

As already stated the South Maslin Sands underlying the Tortachilla Limestone in the coastal sequences on the eastern side of the basin contain only occasional recognizable foraminifera. This is also true for about 50 feet (15 m) of basal quartz sands within the Muloowurtie Formation in the Black Point bore. In the South Maslin Sands, Brown (1960) recorded the foraminifer *Crespinina kingscotensis* while Reynolds indicated that casts of Polymorphinidae and questionable *Gyroidina* are present at Maslin Bay. A *Pseudopolymorphina* sp. which is figured by Ludbrook (1963a) occurs in coastal sections of both the Willunga and Noarlunga Embayments. It is also present with occasional *Maslinella chapmani* and *Cibicides pseudoconvexus* in the basal sands of the Muloowurtie Formation in the Black Point bore. Since the basal marine sequence in the Troubridge and Grange bores contains these foraminifera and planktonics as well, these sands are also likely to be of lowermost Upper Eocene age. The lack of planktonics is attributed to their more marginal positions in the basin. The Troubridge bore is located closer to the open ocean whereas the Grange bore is located nearer the main depositional axis of the basin. Although Ludbrook (1967, Fig. 3) included the South Maslin Sands and part of the Muloowurtie Formation in the Middle Eocene she has not published the evidence. The foraminifera *Globoquadrina primitiva* Finlay which according to Ludbrook (1963a) is diagnostic of Middle Eocene sediments elsewhere has not yet been recorded from areas of possible occurrence in this basin. On the basis of planktonic ranges, it is only possible in this study to correlate formations, parts of formations and equivalents on the eastern side of the basin with those on its western side. Lindsay (1967) defined the upper boundary of the *Turborotalia aculeatea* Zone by the final appearance of the zone fossil within the lower 20 feet (6 m) of the Port Willunga Beds at its type area. In this area, Lindsay indicates that the lower boundary of this zone extends below the Port Willunga Beds and that "the sequence is not at present known to have other planktonics suitable for a basis of zonation until *Hantkenina alabamensis compressa* Parr, is encountered in the lower part of the Transitional Marls". As *H. alabamensis* may range as high as *T. collactea* the lower boundary of the zone can be here defined by the final appearance of *T. collactea*, Finlay and its upper boundary by the final appearance of *Turborotalia aculeata* (Text Fig. 14). The upper beds of the Banded Marl Member and Soft Marl Member, of the Blanche Point Marls, the Chinamans Gully Beds and the basal beds of the Port Willunga Beds were deposited during this time interval.

At Maslin Bay the overlying G. linaperta Zone which is characterised by the final appearance of the zone fossil is of uppermost Upper Eocene age in this basin (Lindsay 1967). The G. linaperta Zone and the T. aculeata zone are concurrently discussed because in some marginal areas of the basin, T. aculeata is either very rare or absent within marine sediments. An additional 20 feet (6 m) of the Port Willunga beds was deposited during the time interval represented by the G. linaperta Zone. In the Willunga Embayment, the presence of G. linaperta within quartz sands between 359 and 400 feet (110 and 122 m) above the Chinamans Gully beds (equivalents) are correlated with Port Willunga beds containing G. linaperta at the coast. On the north-eastern side of this embayment poorly fossiliferous sands underlying sediments of Oligocene age are tentatively correlated with this interval because they intergrade with lignitic sediments considered mainly of Upper Eocene age (p.110).

In the Adelaide Plains Embayment, siliceous limestones and calcareous clays between 1200 and 1540 feet (366 and 469 m) in the Grange bore were deposited during the time represented by the T. aculeata Zone and the G. linaperta Zone (Chart 8). The last occurrence of T. aculeata is recognized in my sample interval at 1300 feet (396 m). In the Hallions bore (Chart 8) sediments at 420 feet (128 m) contain rarely G. linaperta and C. cubensis. The sediments below this level were deposited in paralic conditions

(p. 72) which probably explains the absence of *T. aculeata* high in the Upper Eocene sequence. Parts of formations and formations that belong to this time interval on the western side of the basin are listed below. In the Troubridge bore the first occurrence (down the hole) of *G. linaperta* is found 40 feet (12 m) above the base of the Port Vincent Limestones at 570 feet (174 m) while *T. aculeata* was encountered at 590 feet (180 m). This suggests that the *G. linaperta* Zone is present in this bore. A clay sequence and thin limestones between 610 and 750 feet (186 and 22 m) are included within the *T. aculeata* Zone. In the Black Point bore (Chart 8) *G. linaperta* is first recorded rarely at 180 feet (55 m) in the Rogue Formation. This suggests that the remaining beds of the Muloowurtie Formation, Throoka Silts and part of the Rogue Formation were deposited during this time interval. Planktonics are usually very rare in the upper part of this interval in well-sorted sands of the Rogue Formation which may explain the absence of *T. aculeata* in the Black Point bore. The same formations were deposited within this time interval in their coastal sequences except most of the Rogue Formation is of definite Upper Eocene age at its type area. *Globigerapsis index* Finlay is found near the base of the formation whereas *G. linaperta* and *C. cubensis* are present about 20 feet (6 m) below its top.

In coastal cliffs between Black Point and section 24 south of Port Vincent, the final appearances of both *G.* cf. *linaperta* and *T.* *aculeata* occur within the upper beds of the Rogue Formation. Although sample intervals for the purpose of this study are widely spaced *G.* cf. *linaperta* and *T.* *aculeata* occur together about 5 feet (1.5 m) above the Port Julia Greensand (Member) at section 15 (Chart 3B). Just south of section 16 *G.* cf. *linaperta* occurs without *T.* *aculeata* about 10 feet (3m) above this member. Another diagnostic planktonic form which is associated with *T.* *aculeata* is *T.* (*Globorotalia*) cf. *insolita* Jenkins which is figured by Jenkins (1965, Fig. 13). Only occasional specimens have the high arching aperture as shown by Jenkins. He records the first appearance of *T.* *insolita* above that of *T.* *aculeata*. It is possible that either *T.* *aculeata* is longer ranging or that the first occurrence of *T.* cf. *insolita* is earlier here. Planktonics from this time interval which extend into the Oligocene are shown in Text Fig. 14 . Lindsay notes that juvenile *Globigerapsis* *index* are found rarely in the basal beds of the Port Willunga Beds (type section). Some questionable juvenile forms of this foraminifer are also associated with *T.* *aculeata* in section 15.

Within the middle time interval of the Upper Eocene, several parts of formations and formations which indicate marine regressions and transgressions and non-marine deposition are located in more marginal areas of this basin. In order to correlate these events more closely for the purpose of constructing palaeogeographic maps a discussion of mainly benthonic foraminifera reported by several workers and also those reported in this study is warranted.

Distinctive benthonic foraminifera noted by Carter in Victoria are also present in this basin (Glaessner and Wade, 1958; Ludbrook, 1963a; Wade, 1964). On the eastern side of the basin the benthonics shown in Text Fig.14 persist above the final appearance of *T. collactea* near the base of the Banded Marl Member. *Asterigerina adelaidensis* which was reported by Crespin, 1954 within the Banded Marl Member is not yet known to range higher than this member in other areas (Glaessner and Wade, 1958; Lindsay, 1967).

Besides the *Pseudopolymorphina sp.* (Ludbrook, 1963a) other diagnostic benthonics are also found rarely in the basal sediments of the Port Willunga Beds. The *Pseudopolymorphina sp.* has been considered an appropriate benthonic form for recognizing time-equivalents of the Tortachilla Limestone and Transitional Member by Ludbrook (1963a) and Lindsay (1967). Indeed, this benthonic species is fairly common within this interval. Samples from near the top of the Banded Marl Member are now known rarely to contain this foraminifer at Maslin Bay, and on the wave-cut platform one mile (1.6 km) south of Moana. This foraminifer is present near the base of the Hallions bore in coarse calcarenites.

On the basis of *Asterigerina adelaidensis* (Howchin) Glaessner (1953b) was able to correlate the lower marine beds of Upper Eocene in the Croydon bore on the downthrown side of the Para Fault with those of a similar age in the Kent Town bore on the upthrown side of this fault, and also to the lower beds of the Blanche Point Marls within the coastal sequences.

On the western side of the basin Wade (1964) recorded *Sherbornina atkinsoni*, *Asterigerina adelaidensis* and *Crespinina kingscotensis* within the Muloowurtie Formation located in the coastal area. In this area *Maslinella chapmani* and *Pseudopolymorphina sp.* are also present within the lower half of this formation. In the Black Point bore Ludbrook (1964) recorded a similar assemblage within most of Muloowurtie Formation. In this bore and the coastal section the *Bolivinella sp.* figured by Ludbrook (1963a) and juvenile specimens of *Lamarckina* cf. *airensis* are also present. Benthonic foraminifera which extend throughout the Upper Eocene and are found in sediments of Oligocene age are *Cibicides pseudoconvexus*, *Sherbornina atkinsoni* and *Svratkina perlata*. Near the top of the Muloowurtie Formation and in the subsurface and in the coastal area between Rogue Point and Harts Mine foraminifera become very small and no diagnostic forms are present. The absence of diagnostic foraminifera in the beds may be due to regression that has taken place at different times within the upper half of the Muloowurtie Formation in this area

(p. 130). On the other hand A. adelaidensis and Pseudopolymorphina sp. are not found above the lagoonal Throoka silts in the basal beds of the Rogue Formation. From these considerations, the Muloowurtie Formation above 390 feet (119 m) in the Black Point bore and the coastal exposures probably correlate with the Banded Marl Member and possibly the lowermost beds of the Soft Marl Member of the Blanche Point Marls.

In the Troubridge bore (Chart 8) A. adelaidensis also occurs rarely above T. collactea in glauconitic calcareous clays between 650 and 700 feet (197 and 212 m). In this bore Ludbrook (1963b) records Pseudopolymorphina sp. and Lamarckina airensis between 750 and 850 feet (229 and 259 m) in a limestone sequence. Pseudopolymorphina is not present in calcareous clays between 700 and 750 feet (213 and 229 m) in this bore but at 690 feet (210 m) it occurs in fine calcarenites which indicates that the distribution of this foraminifera is probably controlled by sediment type.

On the eastern side of the basin, Lamarckina cf. airensis has not at present been recorded higher than the Soft Marl Member of Blanche Point Marls. It is usually present in the lower 2/3 of this member. Svratkina perlata and Crespinina kingscotensis and Cibicides pseudoconvexus are also present but are longer ranging. In the Grange bore L. airensis is also present at 1335 feet (407 m) but the range is not certain here because of my widely spread sample interval in this part of the sequence. On the western side of the basin it occurs within the lower half of the Rogue Formation between Port Vincent and Black Point and in the Black Point bore between 225 and 275 feet (69 and 84 m). In the Troubridge bore the first probable occurrence of this foraminifer is at 640 feet (195 m) in a clay sequence. Carter (1964) notes that the final appearance of L. airensis occurs within his Faunal Unit 2 which would also be close to the final appearance of this benthonic form in this area.

On the basis of benthonic planktonic Foraminifera and stratigraphic position within the range of diagnostic planktonics, the lagoonal Throoka Silts probably correlate with the lower part of the Soft Marl Member and equivalents on the eastern side of the basin. The sands near the middle of the Rogue Formation between Stansbury and Black Point are about time-equivalent to the uppermost beds of the Soft Marl Member, the Chinamanb Gully beds and the basal few feet or less of the Port Willunga Beds. While most of this sequence is regressive (p. 151) the upper few feet or less of this sequence is considered transgressive as shown by this sequence encountered in the Black Point bore where it now underlies sediments of Oligocene age. In this bore the uppermost part of this sequence is an approximate time equivalent to the Upper Eocene interval of the Port Willunga Beds.

Correlation of Oligocene Sediments.

Wade (1964) and Lindsay (1967) indicate that Carter's Faunal Units 4 and 5 are difficult to distinguish in the fauna considered of Oligocene age in the St. Vincent Basin. Lindsay questioned the boundary separating Faunal Units 3 and 4 because the "*Globigerina linaperta*" (with swollen chambers) as described by Carter (1958, p.21) is actually *G. angiporoides angiporoides* which is longer ranging than *G. linaperta* (Text Fig. 14). Partly for these reasons, Lindsay defined two new zones, the *Chiloguembelina cubensis* Zone and the *Guembelitria stavensis* Zone by the fauna within part of the Port Willunga Beds at its type section. He indicates that the lower boundary of *C. cubensis* Zone is characterized by the final appearance of *G. linaperta* while the upper boundaries of this zone and the succeeding *G. stavensis* Zone are defined by the final appearance of the zonal fossils (Text Fig. 14). Further Lindsay notes that the upper boundary of the *G. stavensis* Zone is not present in beds exposed at the type section but is found at a higher stratigraphic level in other areas. The overlapping ranges of *Chiloguembelina* and *Guembelitria* were shown by Wade (1964, Table 1). The final appearance of *Guembelitria* is just below the Oligocene-Miocene boundary (Wade, 1964, Lindsay, 1964, 1968). Wade (1964) considers Carter's Faunal Unit 6 as lowermost Miocene (Text Fig. 14). In the Willunga bore these zones are probably present between 276 and 359 feet

(84 and 110 m). Glaessner and Woodard (1956) recorded *Guembelitria* within this interval and Wade (1958, 1964) indicates that it occurs intermittently from 276 to 376 feet (84 and 115 m). Although *C. cubensis* is fairly rare within this interval, it is present at 318 feet (97 m). Wade (1964) also recorded *Cassigerinella chipolensis*, *G. angustiumbilicata* and *G.* cf. *ampliapertura* within this interval. In addition to these foraminifera *G. bulloides*, *G. euapertura*, *Globigerinita unicava* and *Turborotalia opima nana* are also present.

On the basis of the *Sherbornina* lineage Wade (1958) considered that the probable Oligocene-Miocene boundary is located at about 246 feet (75 m) in the Willunga bore where *S. cuneimarginata* and *S. atkinsoni* are fairly common. Occasional specimens of *S. cuneimarginata* showing a similar preservation to those at 246 feet (75 m) are found at lower levels in this bore. They indicate contamination because they show a different preservation from the accompanying foraminifera. Even though the Upper Eocene-Oligocene boundary is now recognized within the Port Willunga Beds Wade's correlation of the Port Willunga Beds (exposed at the type section) with those partly below 246 feet (75 m) in the Willunga bore is valid.

On the northeastern side of the Willunga Embayment arenaceous limestones overlying the lower 40 to 60 feet (6 to 12 m) of the Port Willunga Beds (equivalents) contain *C. cubensis*, *G. stavensis*, *Globigerina euapertura* at lower levels. *C. cubensis* is not recorded near the top of the limestone sequence.

In the Noarlunga Embayment, the *C. cubensis* and *G. stavensis* Zones are present in the Port Willunga Beds located on the wave-cut platform one mile (1.6 km) south of Moana. These zones are also present in continuous cliffs from adjacent to the Onkaparinga River to just north of Moana. In these areas the lower boundary of the *C. cubensis* Zone is found within siliceous limestones about 40 feet (12 m) above the base of the Port Willunga Beds, where as its upper boundary occurs about 80 feet (24 m) above its base. The remaining 40 to 50 feet (12 to 15 m) of mainly bryozoal calcarenites and calcirudites are within the *G. stavensis* Zone. Planktonics associated with the zonal fossils here are *Globigerina euapertura*, *G. angustiumbilicata*, *G. officinalis*, *G. ampliapertura* and *Turborotalia opima nana*.

In the Grange bore in the Adelaide Plains Embayment siliceous beds and arenaceous limestone between 950 and 1200 feet (290 and 366 m) are probably of Oligocene age (Chart 8). The presence of *G. linaperta* at 1200 feet (366 m) substantiates Lindsay (1968) who indicates that the lower boundary of the *C. cubensis* Zone (Upper Eocene-Oligocene boundary) is located near the base of siliceous limestones. In both the Grange and Croydon bores, Lindsay notes that the *C. cubensis* Zone and part of the

G. stavensis Zone are present within the siliceous sequence and that the upper boundary of the latter zone occurs in limestones just above this sequence. In the Grange bore *Guembelitria* has not been found in a core at 972 feet (296 m) but occurs rarely in cuttings at 1,000 feet (305 m). The planktonics *G. euapertura*, *G.ouachitaensis*, *G. officinalis*, *G. angustiumbilicata*, *G.* cf. *ampliapertura* and *Cassigerinella chipolensis* are present in this core. Samples above 972 feet (296 m) were not treated in detail in this bore and only larger benthonic foraminifera were noted. *Operculina victoriensis* and *Calcarina verriculata* (rare) are present at 950 feet (290 m) in the Grange bore. This boundary is considered close to the Oligocene-Miocene boundary which is placed mainly on benthonic evidence.

At 1040 feet (317 m) in the Croydon bore Lindsay (1967) has recorded occasional *Victoriella conoidea* In the coastal area of the Noarlunga and Willunga Embayments *V. conoidea* is common in well-sorted, coarse bryozoal limestones about 15 feet (5m) above the siliceous sequence in the Port Willunga Beds. In the coastal areas it occurs within the *G. stavensis* Zone but may be slightly later in the Croydon bore. The occurrence of *V. conoidea* in this zone corresponds to part of the *Victoriella conoidea* Zone (Faunal Unit 5) of Carter (1964) which was first discussed by Glaessner (1951). Carter records *V. conoidea* from beds of Upper Eocene and Oligocene age in Victoria, but it is not yet known in beds of definite Lower Miocene age.

In the Hallions bore (Chart 8) siliceous rocks and arenaceous bryozoal limestones between 360 and 420 feet (110 and 128 m) are of probable Oligocene age. *G. linaperta* is present at the lower level and the benthonics *Operculina* and *Calcarina* are present at the upper level. *Chiloguembelina* and *Guembelitria* occur rarely within this interval.

Between Black Point and Stansbury the *C. cubensis* Zone and the *G. stavensis* Zone are present within the uppermost beds of the Rogue Formation and Port Vincent Limestone. In the Rogue Formation at sections 15 and 16 (Chart 3B) the local, final occurrence of *C. cubensis* is found about 15 feet (5 m) below the top of the Rogue Formation. Just south of Sheoak Flat it is now found just above the base of the Port Vincent Limestone about 400 feet (121 m) north of section 22. The uppermost occurrence of this fossil north and south of Sheoak Flat gives evidence that the lowermost beds of the Port Vincent Limestone are about time-equivalent to the upper part of the Rogue Formation (p. 148). Further south at section 27 (Chart 3C), *C. cubensis* is present 5 feet (1.7 m) above the base of the Port Vincent Limestone. At these localities, *G. euapertura*, *G, bulloides*, *G. officinalis*. *G. ampliapertura*, *G. angustiumbilicata*, *Guembelitria stavensis* and *Globigerinita unicava* are associated with the zone fossil.

Occasional specimens of *G. stavensis* are present in the remaining beds of the Rogue Formation and Port Vincent Limestone vetween Sheoak Flat and Black Point and the remaining outcrop of the Port Vincent Limestone just south of Sheoak Flat. Planktonics are usually very rare with only occasional specimens of *G. euapertura*, *G. ampliapertura* and *G. officinalis*. Within these beds *S. atkinsoni* and *Svratkina perlata* (Upper Eocene - Oligocene) accompany *G. stavensis* which suggests an Oligocene age. The first appearance of the echinoid *Lovenia woodsi* is found within the *G. stavensis* Zone on both the eastern and western sides of this basin.

Between Port Vincent and Stansbury rare specimens of *Globigernoides quadrilobus primordius* (Banner and Blow) are present with the *G. stavensis* Zone. It is only known from Carter's Faunal Units 5 and 6 (Wade, 1964; Table 1). Just south of Beach Point at section 18 *Operculina victoriensis* occurs within the upper ⅓ of the Port Vincent Limestone with recrystallized *Sherbornina* while midway between sections 28 and 29, the uppermost beds of the Port Vincent Limestone contain *S. cuneimarginata*, *S. atkinsoni* and *O. victoriensis*. The assemblage of foraminifera (Faunal Unit 6, Text Fig. 14) suggests that the Oligocene - Miocene boundary is present within the Port Vincent Limestone at these localities. Further south at Klein Point Ludbrook (1963 a) recorded *S. atkinsoni* near the base of coastal cliffs and

C. cuneimarginata at a higher stratigraphic level within the Port Vincent Limestone. This suggests that the Oligocene-Miocene boundary is also present at this locality.

In the Troubridge bore the cubensis and stavensis zones cannot be recognized within the Port Vincent Limestone because the zonal fossils are either very rare or absent. The lower boundary of Oligocene is tentatively placed at 570 feet (174 m) where G. linaperta is first encountered down the bore hole (Chart 8). From 550 to 570 feet (168 to 174 m), bryozoal limestones contain a similar assemblage of planktonics as those recorded in rocks of Oligocene age in the coastal sequences on the eastern and western sides of the basin (Chart 8). Although planktonics are very rare or absent above 550 feet (168 m) in the Troubridge bore, occasional small specimens of G. stavensis only have been recorded from 520 to 540 feet (159 to 165 m). The Oligocene-Miocene boundary can be only tentatively placed between 450 and 520 feet (137 and 159 m) in this bore. The first appearance (down the hole) of the S. atkinsoni accompanied by S. cuneimarginata is at 450 feet (137 m) but these are extremely rare. Bryozoal limestones at 480 feet (146 m) containing S. cuneimarginata, S. atkinsoni and C. verriculata (all rare) may be close to the Oligocene-Miocene boundary.

In the Black Point bore quartz sands within the Rogue Formation between 110 and 180 feet (34 and 55 m) are of Oligocene age (Chart 8). The first appearance of *G. stavensis* is at 120 feet (36 m). Within this interval planktonic foraminifera in these sands are *G. ouachitaensis*, *G. angiporoides*, *G. bulloides*, *G. angustiumbilicata* and *Globigerinita unicava*. *Cibicides pseudoconvexus* is found rarely near the base of this sequence whereas *S. atkinsoni* is present as high as 110 feet (34 m). *Calcarina verriculata* is present between 80 and 120 feet (25 and 37 m) suggesting that the Oligocene - Miocene boundary occurs either within the uppermost sands of the Rogue Formation or within arenaceous bryozoal limestones (Port Vincent Limestone) at the top of the bore. Single specimens of *C. verriculata* are recorded below 120 feet (37 m) but their preservation suggests contamination.

Sediments of Oligocene age within the Port Vincent Limestone and the Rogue Formation are correlated with Oligocene sediments within the Port Willunga Beds on the eastern side of the basin (Chart 8).

Correlation of Miocene Sediments

Carter's Faunal Units from the base of 6 to the top of 9 (Text Fig. 14) are considered here of probable Lower Miocene age, as shown by Wade (1964). Carter and Wade both consider that Faunal Units 10 and 11 are of Middle Miocene age. In a number of localities on the sides of the basin, planktonic foraminifera are usually poor and for this reason benthonics associated with the available planktonics are used for intrabasinal correlations. In the subsurface of the Adelaide Plains Embayment where planktonic foraminifera are more common, Lindsay (1968) has recognized zones which are mainly based on planktonic foraminifera.

On the eastern side of the basin (Willunga Embayment), the association of *S. cuneimarginata* and *S. atkinsoni* between 110 and 246 feet (34 and 75 m) of the Willunga bore and *Operculina victoriensis*, *Calcarina verriculata* and *S. atkinsoni* within bryozoal limestones exposed in the Sellick Beach area probably represent Faunal Unit 6 (Wade, 1958). These sediments probably constitute the latest known sediments of the Port Willunga Beds in the Willunga Embayment.

In the subsurface of the Myponga Valley, bryozoal limestones between 495 and 661 feet (151 and 202 m) probably represent Faunal Unit 6 and part of Faunal Unit 7.

Operculina victoriensis is common within these sediments and they underlie limestones containing Globigernoides bisphericus, (Dr. Mary Wade, unpubl.). The first appearance of Gdes. bisphericus (Text Fig. 14) occurs within the upper part of Faunal Unit 7 and its final appearance is recognised at the Top of Faunal Unit 10 (Carter, 1958; 1964). Glaessner, (1953a, 1959), Wade (1958, 1964) and Ludbrook (1963a) have recognised Lepidocyclina howchini within sediments penetrated by the Myponga bore. It is present from 352 to 419 feet (107 and 128 m). Dr. Wade (unpubl.) has recorded Gdes. glomerosus in the upper part of this interval. The sediments within this interval are of uppermost Lower Miocene age, i.e. Carter's Faunal Unit 9.

In the Noarlunga Embayment sediments of Lower Miocene age are not yet known within the Port Willunga Beds. It is likely that Miocene sediments occur near the structural axis of this embayment but subsurface material is unavailable from this area.

Between 218 and 400 feet (67 and 122 m) in the Oaklands bore (Adelaide Embayment, Chart 2), Crespin (1954) considered the benthonics Austrotrillina howchini, Operculina victoriensis, Calcarina verriculata, Gypsina howchini and other benthonics are characteristic of a Lower Miocene assemblage. From the lower part of this interval she also listed Sherbornina atkinsoni and Sherbornina sp. nov. (= probably S. cuneimarginata) which suggests the presence of Faunal Unit 6.

The occurrence of *A. howchini* and *G. howchini* and the absence of *Sherbornina* probably indicate the upper part of Faunal Unit 7 and Faunal Unit 8 and 9.

In the Adelaide Plains Embayment, the Port Willunga Beds between 680 and 960 feet (207 and 293 m) in the Grange bore are of Batesfordian to Longfordian age (Lindsay, 1968). This sequence of sediments probably corresponds to Carter's Faunal Units 6 to 8 and most of 9 (Lower Miocene). Lindsay recognizes a *Globigerinoides bisphericus* Zone in both the Grange and Croydon bores while in the Croydon bore two earlier zones (*Globigerinoides trilobus trilobus* zone and *Globigerina woodii woodii* Zone) are present. *Lepidocyclina* is not yet known from these sediments, but is present (lindsay and Shepherd 1966) in sediments of a similar age (Faunal Unit 9) towards the northeastern side of this embayment. Between 211 and 320 feet (65 and 98 m) in Hallions bore, (Chart 8) *Operculina victoriensis* and *Calcarina verriculata* occur within an arenaceous limestone sequence. Occasional specimens of *Gdes. bisphericus* are present at 220 feet (67 m). This fauna probably represents Carter's Faunal Unit 6 and part of Faunal Unit 7.

In the subsurface of the Inkerman-Balaklava area (northwestern side of the basin), about 60 feet (18 m) of quartz sands (p. 100) containing *C. verriculata*, *S. atkinsoni* and other benthonics are considered of Lower Miocene age by Steel (1961). Steel tentatively assigns an Oligocene age to about 10 feet (3 m) of green clays underlying these sands, but the fauna was not studied in detail.

Immediately south of Muloowurtie Point on the western side of the basin (Sect. 5b, Chart 3A), limestones containing the association of *S. atkinsoni*, *S. cuneimarginata* and *C. verriculata* are considered of Lower Miocene age (Faunal Unit 6). It has been previously shown (p. 161) that these limestones and thin basal sands unconformably overlie about 15 feet (5 m) of beach sands constituting the uppermost beds of the Rogue Formation. The first marine bed just below these sands to the south contains *G. linaperta* and *C. cubensis*. This suggests that the faunas diagnostic of the *C. cubensis* Zone and *G. stavensis* Zone are not present at this locality. The limestone sequence above the unconformity is considered about time-equivalent to the sands of Lower Miocene age in the Inkerman - Balaklava area.

Further south of Muloowurtie Point in the Black Point bore the upper 10 feet (3 m) of the Rogue Formation and 20 feet (6 m) of the Port Vincent Limestone contain *C. verriculata*. *S. atkinsoni* is present near the top of the Rogue Formation whereas *S. cuneimarginata* occurs rarely in the Port Vincent Limestone of this bore. The upper 30 feet (9 m) of sediments in this bore, limestones just south of Muloowurtie Point and the upper beds of the Port Vincent Limestone at localities immediately south of Beach Point (p.157) are correlated with the Port Willunga Beds of Lowermost Miocene age, i.e. Faunal Unit 6.

In the Troubridge bore, Carter's Faunal Units 6 and part of 7 are probably present between 380 and 480 feet (116 and 146 m) within the Port Vincent Limestone. C. verriculata and O. victoriensis occur within this interval whereas S. atkinsoni and S. cuneimarginata are found together in the lower 30 feet (9 m) of this interval. Occasional specimens of Gdes. bisphericus occur between 320 and 400 feet (97 and 122 m). Limestones below 400 feet (122 m) also contain this planktonic but their preservation suggests contamination. Ludbrook (1963 b) first recognized Lepidocyclina within bryozoal limestones between 280 and 320 feet (85 and 97 m) and correlated them with the Melton Limestone on the northern part of Yorke Peninsula. In this bore, the interval from 280 to 480 feet (85 to 146 m) within the Port Vincent Limestone are correlated with sediments of Lower Miocene age (Faunal Units 6,7,8 and part of 9) within the Port Willunga beds on the eastern side of the basin. In the Troubridge bore, the Lower Miocene-Middle Miocene boundary may be present in 80 feet (24 m) of limestones above beds containing occasional Lepidocyclina, but there is no faunal evidence to prove this. On the other hand, sediments of Middle Miocene age occur in the subsurface of Adelaide Plains Embayment. Lindsay and Shepherd (1966) have shown that Munno Para Clay Member of the Port Willunga Beds is of uppermost Batesfordian and lowermost Balcombian age (parts of faunal Units 9 and 10).

The Balcombian is considered of Middle Miocene age (Carter, 1964; Wade, 1964 and Ludbrook, 1967). Lindsay (1968) also recognized sediments of Bairnsdalian age (Faunal Unit 11) from this area.

Palaeoecology

A general study of groups of foraminifera was attempted for the purpose of determining the relative depths of water in which the sediments of more marine character were deposited. A preliminary study of the prolific fauna within these Tertiary sediments is warranted because the greatest thickness of marine sediments deposited within a time interval may not indicate the area of greatest tectonic movement. Though ranges of depths are presented, these are considered tentative.

A statistical analysis of foraminifera was undertaken from sediments encountered in the Troubridge bore. Though contamination was present within sample cuttings, the preservation of foraminifera from different levels could usually be distinguished. A statistical analysis was also attempted on foraminifera obtained from the coastal sequence located on the wave-cut platform one mile (1.6 km) south of Moana, where foraminifera were extracted from samples of the Blanche Point Marls and Port Willunga Beds. Three samples from the Tortachilla Limestone and two samples from the Blanche Point Transitional Marl Member were also examined but these were obtained from Maslin Bay, located on the opposite side of a structural high.

The statistical analysis is based on dominant groups of foraminifera (Chart 9). Washed samples were reduced to a suitable size by the cone-and-quarter method.

The number of specimens examined from individual samples varied between 300 and 800. Specimens were mounted from samples obtained from the Moana area whereas due to the large number of samples in the Troubridge bore, specimens were spread out on trays and counted. Groups of foraminifera totalling at least 5% were considered significant. Identifiable contamination of foraminifera in the Troubridge bore was eliminated from the count and the trends are comparable with other stratigraphic data elsewhere in the basin.

Within the marine sequence of the Troubridge bore, the Cibicides group constitutes the largest percentage of benthonic foraminifera. This is also true from both statistical data and general observation, within most local sequences of good marine character. The other significant groups of benthonics in sediments of Upper Eocene and lowermost Oligeocene age in the Troubridge bore are the Angulogerinid, Cassidulinid and Miliolid groups (Chart 9).

Small numbers of Uvigerina have been included within the Angulogerinid group. There are three peaks which show greater percentages of this group (Chart 9). The earliest and latest of these three peaks also coincide with the maximum percentages of planktonics whereas the intermediate peak coincides with an insignificant percentage of planktonics.

Below 750 feet (229 m) and above 390 feet (169 m) low percentages of Angulogerinids occur in moderately-sorted biogenic limestones whereas between 540 and 750 feet (166 and 229 m) fluctuating percentages of this group are found within finer sediments. The greatest percentage recorded within the Miliolid group is found at 690 feet (210 m) and a slightly lower percentage peak is present at between 610 and 620 feet (186 and 189 m). Within these intervals the higher percentages of Miliolids correlates with low percentages of the Angulogerinids. Although the sediments between 670 and 690 feet (204 and 210 m) are considered marine small numbers of foraminifera are not statistically valid. The foraminiferal population here mainly consists of a greater number of juvenile specimens. This interval of sediments and those including a higher percentage of Miliolids and lower percentages of the Angulogerinid group are found at a stratigraphic level similar to those sediments indicating either regressive or lagoonal deposition within the subsurface and coastal sequences between Stansbury and Rocky Point. The point on the percentage graph of angulogerinid group is comparable with regressive and transgressive marine sequences on the western side of the basin. In the Troubridge bore there is one exception to the trends of these groups above 570 feet (174 m), but this is considered due to a change in palaeogeographic configuration of the marine basin (p. 223).

The results of this study suggest that in the Troubridge bore and other areas only general limits can be placed on the possible depth of water where sediments of Upper Eocene and lowermost Oligocene age accumulated on the sea floor. In the Troubridge bore, two intervals of finer grained sediments containing significant percentages of planktonics (Chart 9). This. is in direct contrast to other parts of the basin where planktonics are usually very rare. On the basis of poor planktonics in most of this basin, the configuration of the marine basin was considered restricted from the open sea (Glaessner and Wade, 1958). In this bore, the high percentage of planktonics is supporting evidence that Investigator Strait was the main connection to the open sea during the Upper Eocene and lowermost Oligocene. From Recent sediments collected from the floor of the St. Vincent Gulf, Cooper (1960) showed the distribution of foraminifera (at generic level) in different areas. He noted that planktonics were common in sediments collected from the sea floor of Investigator Strait and rare within sediments of the Gulf proper. If wind velocity was no greater than at present, the orbital action of waves over most of the marine parts of the basin would show a maximum depth of 8 fathoms only during brief storms. At other times, the depth at which finer detritus could be deposited would be less than 8 fathoms (C. C. Von der Borch, pers. comm.)

Several workers have indicated from Recent and Tertiary distribution of benthonics that significant numbers of porcellaneous types of foraminifera (Miliolids) occur within littoral and shallow water environments. Large numbers of these are mostly recorded in Recent sediments above 30 fathoms. Sediments containing between 10 and 30% of Miliolids were probably deposited within these limits. On the other hand, they may not be present in shallow water because of other factors in the physico-chemical environment. Although the greater percentage trends of the Angulogerinids tend to suggest depths of water below 30 fathoms, the depths of water in which these sediments were deposited can only be defined within broad limits because not enough is known of their Recent distribution on sea floors. Within sediments containing the maximum percentages of the Angulogerinids, *Cibicides* still forms at least 30% of the total population (Chart 9). A large percent hinders depth control because they can live at most shelf depths (Glaessner, 1945). *Angulogerina angulosa* which forms substantial numbers in some samples may indicate depths between 20 and 40 fathoms, or less as suggested by Walton (1955) for Recent sediments in the Todos Santos Bay, California.

On the eastern side of the basin at Maslin Bay, the South Maslin Sands are excluded from the discussion here because foraminifera are either rare or mainly consist of clay moulds. The lowermost calcareous beds of the Tortachilla Limestone contain small percentages of both the Angulogerinid and Miliolid groups.

In the remaining part of the Tortachilla Limestone and overlying Transitional Marl Member at Maslin Bay and the Banded Marl and Soft Marl Members of the Blanche Point Marls immediately south of Moana, the Angulogerinid group probably shows significant trends (Chart 9). Although the maximum percentage of this group occurs within the Banded Marl Member, the percentage difference between this member and the lower 1/3 of the Soft Marl Member is small. These sediments may have been deposited within a similar depth of water. Within the upper 2/3 of the Soft Marl Member, the percentage trend of this group decreases upwards in the sequence with minor oscillations near the top. The Miliolid group here forms only small percentages of the total population reaching a maximum of 10% near its top (Chart 9). In the upper few feet or less of this Soft Marl Member the foraminifera are usually poor and mostly species are represented by juvenile specimens. Reynolds (1953) noted this for sediments of this member located just below the Chinamans Gully Beds at Aldinga Bay. It is also true for marine sediments underlying lagoonal sediments in other areas of the basin. Landward of the coastal section in the Willunga Embayment, it has been already shown on stratigraphic criteria that most of the Blanche Point Soft Marls (mostly clays and silts) are regressive as they are intercalated with shoreline and fluviatile sediments (Chart 5).

The Angulogerinid group appear to conform to this shallowing of water, but large percentages of Miliolids are not as common as would be expected from trends on the opposite side of this basin. This is probably due to ecological factors because Miliolids are fairly common (25 to 75% levels) in the Muloowurtie Formation. The high percentages in the Miliolid group are somewhat similar to the greater distribution of Miliolids in Recent sediment on the sea floor immediately west of Yorke Peninsula where they occur at depths less than 12 fathoms (Cooper, 1960). On the southern side of the Noarlunga Embayment both Cassidulinids and Bolivinids were most important during deposition in the Blanche Point Marls. They decrease to an insignificant percentage toward the top of the Soft Marl Member and near the base of the Blanche Point Marls.

In the Adelaide Plains Embayment, the Grange bore contains the maximum accumulative thickness of Upper Eocene and Oligocene marine sediments. Foraminiferal trends were not compiled in detail because contamination was particularly heavy, but cores near the base, middle and top of this sequence showed relatively high percentages of the Cibicides, and Angulogerinids. Miliolids, although present, did not appear to form large percentages of the total population.

An important change within the frequency of foraminifera groups takes place in sediments of Oligocene age in some areas of this basin.

Excluding the Cibicides group, most other groups of Upper Eocene and lowermost Oligocene age decrease in frequency above the uppermost percentage high of the Angulogerinid group (Chart 9). There are several other groups that now become relatively significant. On the western side of the basin Notorotalia howchini and Eponides are fairly common within bryozoal limestones in the Troubridge bore (Chart 9) and also within bryozoal limestones located near the base of coastal cliffs between Beach Point and Stansbury. On the opposite side of the basin Victoriella conoidea, Textularia and Eponides are abundant within bryozoal limestones above fine grained sediments in the Port Willunga Beds at Moana (Chart 9), in coastal cliffs immediately south of the Onkaparinga River and between Aldinga and Snapper Point. From the previous discussion, it would seem that the decrease in frequency of the Angulogerinid group would probably indicate a decrease in water depth. One could argue that the Miliolid and Angulogerinid groups of an earlier age preferred a different type of marine sediment, but biogenic limestones within the earlier sediments contain these groups. On the other hand, there is stratigraphical evidence that selective sorting is the most likely cause in the different frequencies of foraminiferal groups and that a major change in the palaeogeographic configuration of the marine basin has taken place.

On the eastern side of the basin the Port Willunga beds are mainly a transgressive sequence (Glaessner, 1953 b). On its western side, the Port Vincent limestones are also a transgressive sequence. It is considered that within the time interval of the G. stavensis Zone the St. Vincent Basin became less restricted and that the sea covered most of the southern parts of Yorke Peninsula. Even though remnants of bryozoal limestones overlying Permian basement near the middle of Yorke Peninsula (Crawford, 1965) probably have been deposited slightly later as suggested by transgressive sequences elsewhere, they attest to the fact that sea did cover part of Yorke Peninsula. Since there was then a more open connection between this basin and the open ocean, the depth of wave base was thus likely to increase from 8 fathoms to slightly less than an open shelf wave base of 40 fathoms. Most of the bryozoal limestones show current sorting and most of the larger, thick shelled benthonics probably lived between 8 and 40 fathoms.

In the Grange bore (Chart 8) argillaceous limestones within the uppermost Oligocene, particularly within a core at 970 feet (296 m) contain numerous planktonics and Angulogerinids suggesting that greater depths were present near the structural axis of the Adelaide Plains Embayment than on the western side of the basin or more marginal areas on its eastern side.

Several groups of large benthonics become abundant at various intervals within bryozoal limestones of Miocene age. Cibicides is still the dominant benthonic present, Operculina victoriensis and Calcarina verriculata are also common. Operculina can be found at shelf depths whereas Calcarina is common from below littoral depths to 20 fathoms but may range down to 60 fathoms (Adams, 1965). In the Troubridge bore Notorotalia howchini and Eponides now decrease in abundance and the presence of C. verriculata which becomes slightly more common higher in the sequence may suggest slightly shallower water. This benthonic, together with Lithothamium and marine barnacles, occurs in a sequence of bryozoal limestones south of Sellick Beach. These sediments were probably deposited at depths less than 20 fathoms. A similar depth was probably present near Muloowurtie Point with arenaceous bryozoal limestones, containing Calcarina and Sherbornina . Sherbornina probably occurred at depths similar to Calcarina but preferred either an arenaceous lime or quartz sand substrate. The presence of Lepidocyclina which commonly lived at depths between 25 and 40 fathoms, but may also have lived within depths less than 5 fathoms (Adams, 1965) occurs in more marginal areas of this basin. The absence of this benthonic from the Grange bore, and usually poorly-sorted limestones, suggests slightly deeper water during this time within the Miocene sequence.

Climate

A humid climate is indicated during the Tertiary by the accumulation by fluviatile sediments because swamp deposits on floodplains are numerous and widespread on the margins of the St. Vincent Basin and adjacent "Upland Areas". The climate was more humid than today because there is definite lack of salt deposits which are now forming in some areas adjacent to the St. Vincent Gulf. The formation of Eocene laterites also indicate a humid climate, but the presence of mainly kaolinite within soil profiles and in early Tertiary fluviatile sediments as well suggests a less extreme climate than tropical, probably temperate.

Glaessner (1959) proposed a cool climate on the basis of cool water foraminifera during the Upper Eocene. Wade (1958, 1964) showed that *Lagenids* and the *Globigerina bulloides* Group indicated cool water during this time interval. On the basis of larger foraminifera, Miogypsinidae and Lepidocyclinidae, Crespin (1956), Glaessner (1959) and Wade (1958, 1964) indicated that warm water currents were present in this basin during the Uppermost Lower Miocene, but this assemblage and planktonics (see Wade, 1964) indicate less warm conditions than in the tropics. On the basis of mainly mollusca Ludbrook (1958, 1963) indicated warm water forms during the Pliocene.

Dorman (1966) on the basis of oxygen isotope determinations on molluscan shells in Victoria notes a cool climate during the Eocene followed by a gentle warming to the highest point in the Batesfordian then a temperature drop in the Middle and Upper Miocene.

CHAPTER 4

PALAEOGEOGRAPHY

The geography of the St. Vincent Basin during the Tertiary is portrayed in Text Figs. 15-17. Although subsurface data are still inadequate for much of this basin, stratigraphic data which have been placed in the basin-wide time-framework (Chapter 3) permit reconstruction of the major physiographic features during the Tertiary.

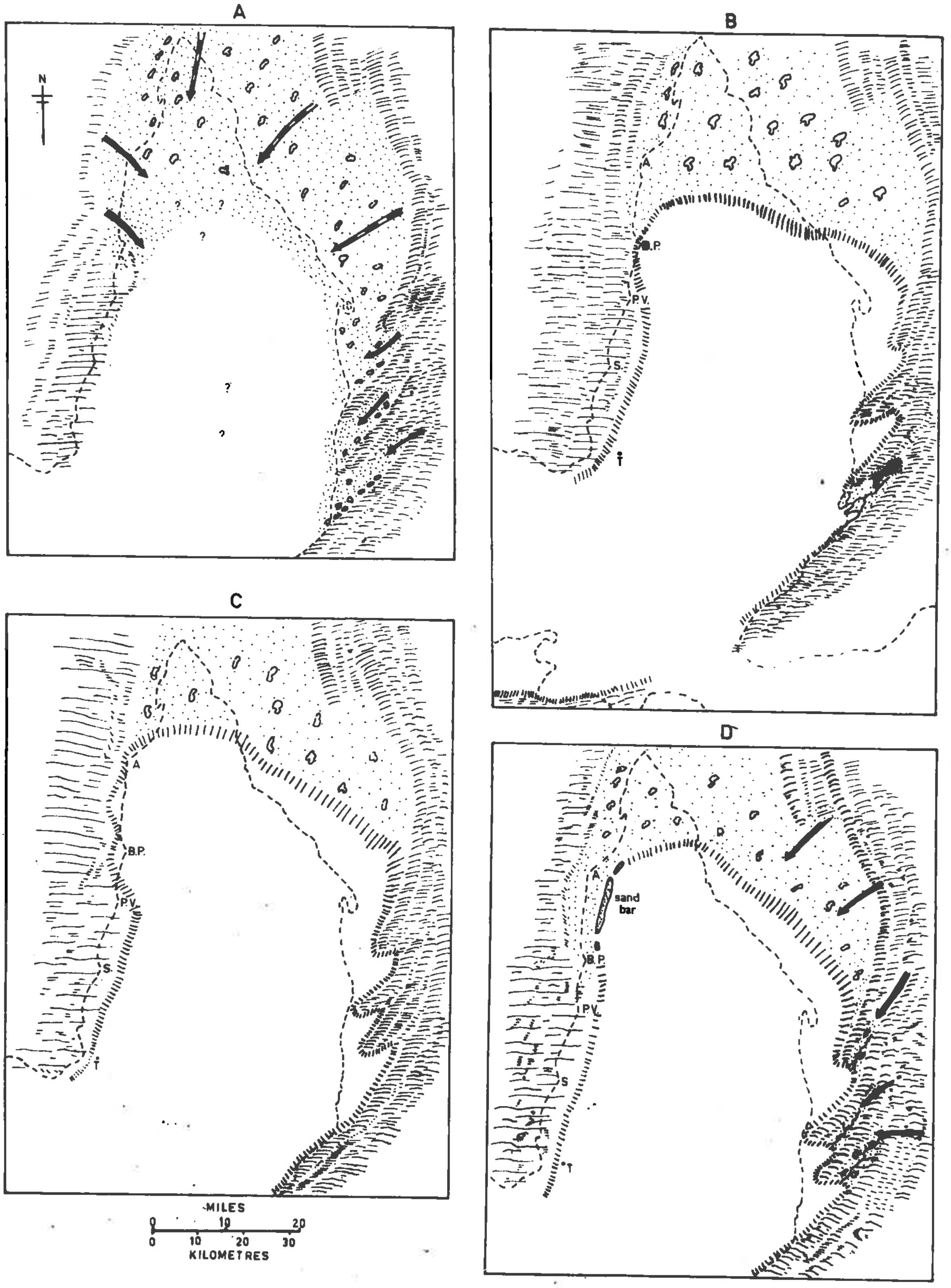
Phase 1

The influx of Middle Eocene fluviatile sediments into the St. Vincent Basin marked the beginning of basin development. This phase of aggradation was initiated by rejuvenated mild uplift of the Mt. Lofty Ranges and neighbouring land the northern side of the basin and subsidence in the basin. Streams flowing from the land areas transported coarse and fine detritus to low areas in the basin. The landscape during the deposition of the North Maslin Sands and Clinton Coas Measures is reconstructed in Text Fig. 15A. The arrows indicate provenance.

Text Figs. 15, 16 and 17 Palaeogeographic Maps, St. Vincent Basin and adjacent areas; maps show areas of fluviatile and marine deposition in Middle Eocene, Upper Eocene, Oligocene, Lower Miocene and Upper Pliocene times, and indicate advances and retreats of the Tertiary sea. The specific time each map illustrates is listed below:

A. An instant within Middle Eocene time
B. Earliest proven Upper Eocene time
C. Lower part of Upper Eocene *Turborotalia aculeata* Zone
D. Slightly later time in the *T. aculeata* Zone; Lower part of the Blanche Point Soft Marls, Throoka Silts and equivalents
E. Slightly later time represented in Upper Eocene Blanche Point Soft Marls
F. Near the top of the *T. aculeata* Zone
G. An instant in Upper Eocene *Globigerina linaperta* Zone
H. An instant in the Oligocene *G. stavensis* Zone
I. An instant in lowermost Lower Miocene time
J. An instant in Lower Miocene time
K. An instant in Upper Pliocene time.

TEXT FIG. 15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sand bar
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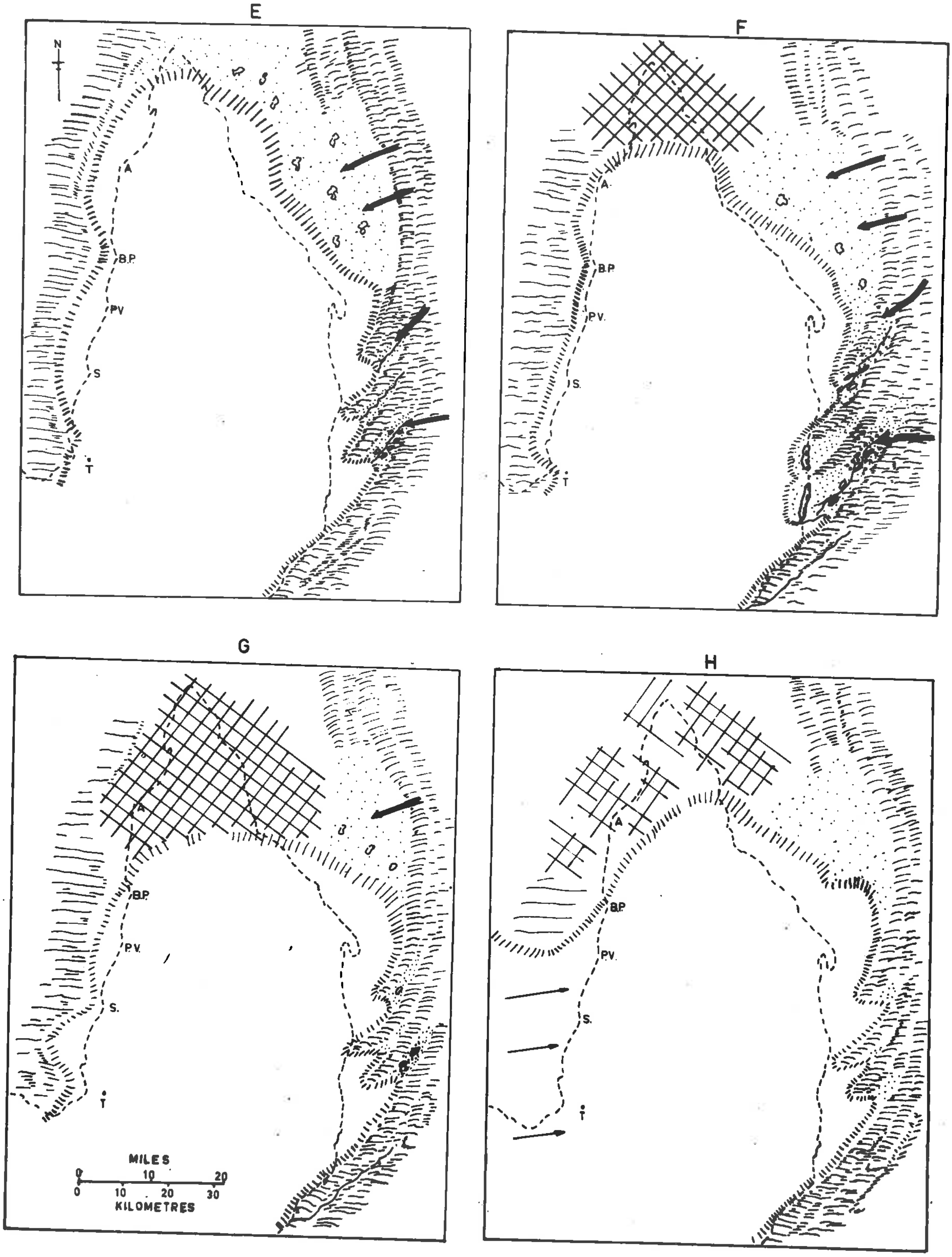
KILOMETRES

TEXT FIG. 16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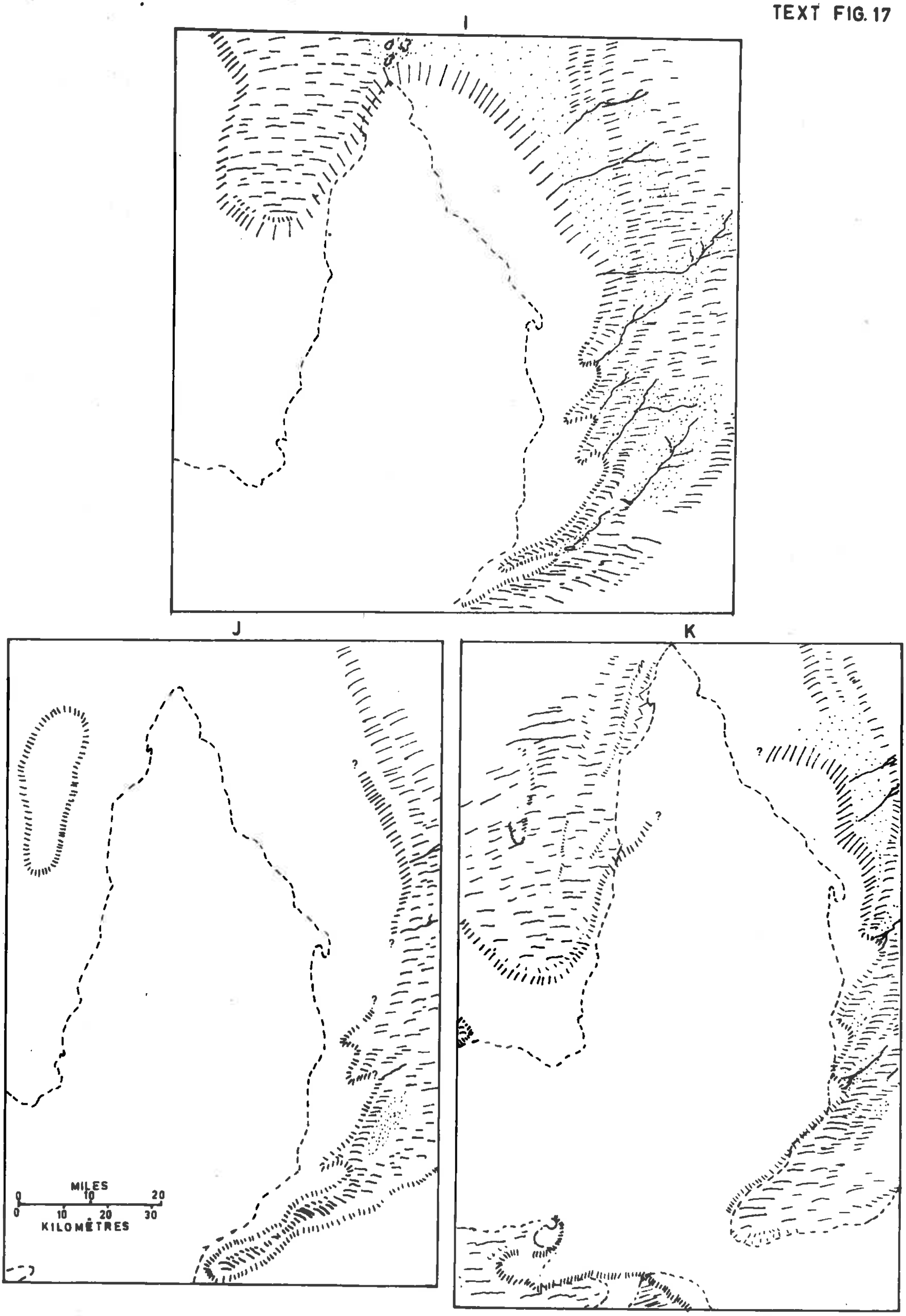
TEXT FIG. 17



Phase 2

The next phase is documented by marine sediments deposited during the early part of the time-unit representing earliest definite Upper Eocene age. The distribution of sea and land is shown in Text Fig. 15B. The sea probably did not reach the northern areas of the basin where the accumulation of fluviatile deposits continued, while marine deposition took place in more southerly parts of the basin. Estuarine sediments (South Maslin Sands) accumulated in parts of the Willunga Embayment (Brown, 1960) while fluviatile deposition continued in the remainder (Text Fig. 15B), but slightly later, marine deposition also occurred in this area (p. 52). In sinking areas near the axis of the embayments marine deposition continued while a retreat of the sea occurred on the sides of the Willunga and Noarlunga Embayments (p. 239). There is no evidence to suggest a retreat of the sea from either the area between the Adelaide and Adelaide Plains Embayments or the remaining parts of the basin. The sea probably continued to advance in these areas to a maximum shown in Text Fig. 15C which represents an instant in Upper Eocene time within the lower part of the Turborotalia aculeata Zone in the Blanche Point Banded Marl and in the upper half of the Muloowurtie Formation.

Phase 3

On the western side of the basin the uppermost beds of the Muloowurtie Formation and equivalents indicate a retreat of the sea (p. 130). On the eastern side of the basin the sea also begins to retreat from the sides of the embayments during the accumulation of the Blanche Point Soft Marl Member (or equivalents). Text Fig. 15D represents a slightly later instant in Upper Eocene time showing the retreat of the sea in these areas. Lagoonal, swamp and stream sediments (Throoka Silts to the west) were accumulating adjacent to this sea in many areas of the basin (Text Fig. 15D). At about this time, mild uplift of the Mt. Lofty Ranges becomes more pronounced and streams have cut into high grade metamorphic rocks in parts of the Ranges. The sea continued to retreat from the embayments and this was accompanied by an advance of the sea on the western side of the basin. The maximum advance of the sea shown (Text Fig. 16E) represents an instant in time during the accumulation of sediments in the lower part of the Rogue Formation and equivalents. Slightly later in Upper Eocene time, the maximum probable extent of mainly fluviatile deposition (Chinamans Gully Beds and other beds) on the eastern side of the basin was complemented by another retreat of the sea on its western side. An instant near the top of the Turborotalia aculeata Zone is shown in Text Fig. 16F. It represents another stillstand reached on the west and east sides of the basin though an unconformity on its northern side indicates the beginning of non-deposition or erosion.

Phase 4

The retreat of the sea from the northern side of the basin (Text Fig. 16F) probably continued during the uppermost part of the Upper Eocene Turborotalia aculeata Zone, as the time-span of the unconformity diminishes to the south. It probably did not extend much further south than the inferred shoreline indicated in Text Fig. 16G which represents a stillstand at the northern side of the basin and an advance of the sea in the embayments and in areas south of Black Point on York Peninsula. This advance of the sea continued in these areas but it probably did not advance much on the northern side of the basin during the Upper Eocene Globigerina linaperta Zone and Oligocene Chiloguembelina cubensis Zone. An instant in the Globigerina linaperta Zone is shown in Text Fig. 16G.

The deposition of the Port Willunga beds and equivalents commenced in the top of the *Turborotalia aculeata* Zone following immediately on sediments indicated in Text Fig. 16F. A general advance of the sea is shown in Text Fig. 16-17G to J inclusive.

The sea (Text Fig. 16G) continued to advance on the southern part of Yorke Peninsula during the Oligocene *Chiloguembelina cubensis* Zone, and at a slightly later time within the Oligocene *Guembelitria stavensis* Zone most of the southern portion of Yorke Peninsula was covered by this sea as shown in Text Fig. 16H. This Map indicates a major change in the marine configuration of the area and deposition took place in a more marine environment. The sea (Text Fig. 16H) had mostly covered areas of non-deposition or erosion on the northern side of the basin as indicated in Text Fig. 17I which indicates an instant in lowermost Miocene time. It also advanced further north on Yorke Peninsula, onto a basement high immediately south of the Willunga Embayment and into the "Upland" Myponga Valley. Text Fig. 17J which represents an instant in time during the uppermost Lower Miocene indicates that the sea probably covered most of Yorke Peninsula except for a small island while a great area of Fleurieu Peninsula was probably covered by this sea, but the remainder of the Mt. Lofty Ranges was still emergent.

Backstairs Passage was probably opened at this time.

Text Fig. 17I also indicates that known Mid-Tertiary fluviatile deposition probably commenced in the lowermost Lower Miocene in two known "Upland Areas". The general advance of the sea during the Lower Miocene time and possibly lowermost Middle Miocene time was not continuous. This is well documented by swamp deposits underlying sediments of uppermost Lower Miocene age and possibly also interbedded within them, while towards the northeastern side of the Adelaide Plains Embayment they occur within marine sediments of Lower Miocene age. It is likely that swamp deposition occurred during the lowermost Lower Miocene or slightly earlier on at least the northern side of the basin (as indicated in Text Fig. 17I) because they overlie Upper Eocene sediments and by uppermost Miocene time the sea had covered this area (Text Fig. 17J). Middle Miocene marine sediments are definitely known from only the Adelaide and Adelaide Plains Embayments though they must have accumulated in the general advance of the sea. Available evidence in surface exposures and the subsurface indicates a period of erosion which took place between the deposition of lower Middle Miocene and Lower Pliocene sediments. The Miocene sea had retreated from known areas of marine accumulation and probably from the remainder of the basin as well.

Phase 5

During the Lower Pliocene, the sea returned to the basin as indicated by marine sediments of this age in the Adelaide Plains Embayment (p.165). Slightly later, during an instant in Upper Pliocene time, parts of Yorke Peninsula, Kangaroo Island and areas on the eastern side of the basin are now submerged (Text Fig. 17K) and the marine configuration of the landscape again indicates a fairly restricted basin.

CHAPTER 5

BASIN DEVELOPMENT

It is suggested from this study that the St. Vincent Basin is an intracratonic basin. This is shown by the following facts:

1) A major orogeny has not occurred since the Lower Palaeozoic.
2) The low relief during the accumulation of Tertiary sediments was typical of local areas adjacent to the St. Vincent Basin.
3) Thin sequences of Tertiary sediments were formed in the basin proper and adjacent areas.
4) Very mild structural movements were taking place during the Tertiary.
5) Faulting movements along ancient fault lines suggest that the depositional axis, the main axis of accumulation, is located at about 90° to the continental shelf. Because of this fact this basin is unlike other marginal basins situated near the present continental shelf.

Throughout the Tertiary the eastern side of the basin has been defined by the inter-action of a series of sub-parallel faults and a hinging movement which resulted from differential rates of movement adjacent to ancient faults. The greatest overall accumulation of sediments has been deposited adjacent to the Para Fault in the Adelaide Plains embayment (Chart 8). Progressively less sediment has been accumulated in embayments to the south and the northern and western sides of the basin. The slightly east-of-north trend of structures on the western side of the basin, converging with the more northerly trend of arcuate faults on the eastern side makes the northern end of the basin a triangle filled with largely non-marine sediment as is shown by the palaeogeographic maps (Text Figs. 15 and 16). These sediments have been derived from surrounding areas.

Evidence of change in areas of maximum relief of the Mt. Lofty Ranges is provided by heavy minerals in the North Maslin Sands, Golden Grove Sands and the Bakers Gully Sands. This is indicated by streams crossing the Willunga Fault east of Clarendon, and the Eden - Burnside fault. Fluviatile sediments become progressively younger towards the margins of the basin and in the Ranges; the overlap of younger marine sediments onto basement on the western and northern sides of the basin indicates that only very mild structural movements were taking place on the rims of the basin and adjacent areas. This is typical of intracratonic basins.

The structural movements of very mild uplift of the Ranges and subsidence in the basin along linear elements is superposed on a more widespread (possibly epeirogenic) movement which can be seen in the widespread transgression of the Port Willunga Beds (Glaessner and Parkin, 1958), the regression in Upper Miocene time and renewed Pliocene transgression. All three of these affected neighboring areas and extended far beyond the limits of the basin. This type of movement probably also influenced earlier formations, but there are linear structural movements which have taken place during the Tertiary.

Structural Movements in the Eastern Area

In the eastern area different thicknesses of fluvial North Maslin Sands adjacent to ancient faults indicate that greater rates of cumulative subsidence occurred on the present downthrown sides of the faults after they were covered by marine or estuarine sediments. The formation of a finer grained facies adjacent to the Clarendon - Moana fault with a coarser grained facies on the northern side of the Noarlunga Embayment serves as a model which attests to greater subsidence adjacent to this fault. The absence of a thick conglomerate facies adjacent to these faults indicates that relatively slow cumulative subsidence occurred in these embayments. Except for occasional erosional hollows, the highly weathered basement indicates that the basement surface was relatively flat. An ancient fault-line scarp (Clarendon - Moana Fault) was present, but the relief of this scarp was very low as indicated by the absence of a conglomerate facies.

There was a rejuvenation of movement along the Clarendon - Moana fault-line after the deposition of the North Maslin Sands and laterite formation. This uplift of the high separating the Willunga and Noarlunga Embayments was greater landward of the present coast than the high separating the Noarlunga and Adelaide Embayments. The increased uplift of the southern high is indicated by the greater stripping of the North Maslin Sands especially from the northeastern side of the Willunga Embayment (Map 4). This uplift supplied reworked detritus including laterite fragments to the mainly estuarine South Maslin Sands and equivalents in subsiding areas. The antiquity of movements of this high is confirmed on its opposite side where the South

Maslin Sands indicate more marine influence near the present coast than in landward areas. Relative uplift of the northern high was less than of the southern high as indicated by the widespread distribution of the South Maslin Sands in the Noarlunga Embayment. In this embayment greater subsidence was taking place adjacent to the Clarendon - Moana Fault as indicated by the South Maslin Sands grading to mainly clays near the axis of the embayment.

The movements of rising or relatively stable highs and subsiding lows are confirmed by the stratigraphic relationships of the Tortachilla Limestone and lowermost beds of the Blanche Point Marls; they overlap earlier formations onto basement (Glaessner, 1953b) but in deeper parts of the embayments, adjacent to ancient faults, there is no evidence to suggest unconformable relationships between the Tortachilla Limestone (or equivalents) and the South Maslin Sands (Chart 5, 6 and 7). It is suggested that marine accumulation (relative subsidence) was probably continuous in these areas. In the Adelaide and Adelaide Plains Embayments, marine deposition was continuous on the downthrown sides of faults. Relative subsidence was less on the upthrown side of the Para Fault as indicated by the thinning and diachroneity of the lowermost marine beds.

The facies distribution of the Blanche Point Banded Marl Member (Map 6) indicates that greater areas of subsidence were occurring adjacent to ancient faults in the form of a hinge movement or slow tilting towards the southwestern parts of the embayments. In the Noarlunga Embayment, the absence of a deeper water clay and silt facies suggests that relative subsidence was more uniform throughout this embayment and it behaved more like a slowly subsiding tectonic unit with the Willunga Embayment. This was also the case during the Pliocene as suggested by Twidale et al. (1967) where little movement occurred adjacent to the Clarendon - Moana Fault. On the other hand, in the Adelaide Plains Embayment thick Pliocene marine beds on the downthrown side of the Para Fault and thinner beds of the same age on its upthrown side (Text Fig. 11) also indicate that ancient fault lines were boundaries between more or less subsiding areas. During the deposition of the Blanche Point Soft Marls the embayments acted independently again with areas of main accumulation adjacent to faults. On the southern side of the Noarlunga Embayment the preservation of the non-marine Chinamans Gully Beds (Map 5) suggests that fluviatile deposits are present throughout most of this embayment. Subsidence was again fairly uniform throughout the Noarlunga Embayment whereas thicker small scale paralic sequences near the axis of the Willunga Embayment indicate that this area was undergoing relatively greater subsidence adjacent to the Willunga Fault (Chart 5). The Adelaide Plains Embayment was undergoing the greatest relative amount of subsidence as thick marine deposition was continuous in this area adjacent to the Para Fault (Chart 6). This was probably also the case adjacent to the Eden - Burnside Fault Zone in the Adelaide Embayment (Chart 7). The greatest amount of subsidence occurred adjacent to the Para Fault, comparable to the other embayments and the remainder of the basin, took place during the uppermost Upper Eocene and Oligocene (Chart 8).

On the northern side of the Noarlunga Embayment, the unconformities either above or below the Chinamans Gully Beds suggest that the structural high separating the Noarlunga and Adelaide Embayments had periods of gentle uplift when compared with the remaining structural highs. This is also evidence that movements along the ancient fault-lines were independent of one another.

In the Willunga Bore No. 1 clays, silts and sands of Upper Eocene and Oligocene age (Chart 5) suggest that the structural high immediately south of the Willunga Fault was a very low positive area (Chart 2, Text Figs. 15 and 16) for most of this time interval, with subsidence being the main form of movement in the Willunga Embayment. A reversal of movement occurred in the south during the deposition of the Lower Miocene sediments as these sediments transgress over the Willunga Fault. Periodic movements of uplift south of the fault zone are suggested by intraformational slump structures (Glaessner, 1953b) but these did not dominate over subsidence movements in this area until pronounced folding movements occurred between the Middle Miocene and Lower Pliocene.

Northern Side of the Basin

In the northern area the basal fluviatile flood-basin sediment is not typical of sediments deposited adjacent to faults which showed an appreciable relief. Instead, these sediments indicate that movements were very slow in this area, as they were deposited over a long length of time.

At Muloowurtie Point unconformable relationships between Upper Eocene and Miocene sediments indicate that movements were still taking place adjacent to ancient fault-lines. However, the large area which this unconformity covers suggests that the northern end of the basin was very mildly uplifted while the accumulation of marine sediments continued in other parts of the basin (Text Fig. 15). The independence of movements in the basin is shown by the transgression of the Port Willunga Beds and Port Vincent Limestone in the southern parts of this basin which was undergoing subsidence while it took longer for the northern area to once again undergo subsidence.

Western Side of the Basin

Following the accumulation of fluviatile deposition in the vicinity of Black Point, the separation of fluviatile sediments in the coastal sequence (Chart 3A) from those in the subsurface (Chart 4) indicate that north - south faulting occurred in this area prior to the deposition of marine sediments. The displacement of beds was less than 200 feet (60 m). The northern part of Yorke Peninsula (Chart 3A, Map 1) appears to be a block (A) separate from the southern areas as indicated by the accumulation of the Upper Eocene Muloowurtie Formation. Slight tilting of the northern block towards the St. Vincent Gulf and to the north is indicated by the absence of these beds on the western side of the Peninsula and facies relationships of the high energy Quartoo Sand Member intertonguing with the main body of the Muloowurtie Formation in a northerly direction. The northward tilting of this block is also indicated by facies of mainly quartz sands in the Rogue Formation grading to more carbonate-rich rocks in a northerly direction. South of Black Point the absence of the Muloowurtie Formation or equivalents from on the east coast of the Peninsula suggests that a north -- south fault-line is present in this area. These beds gradually accumulated in this slowly subsiding area which was adjacent to this fault as they are present in the Troubridge bore (Chart 4). This substantiates a statement by Crawford (1965) who considered that a fault-line was present in this area. The northern and southern blocks (A-B) acted as a single tectonic unit during the deposition of the lagoonal Throoka Silts; they and shallow water marine equivalents are recognized in both areas suggesting uniformity of movement.

The tilting of the northern block and times of interdependence of the movements along the east coast of Yorke Peninsula suggest that an east - west fault is also located in the vicinity of Black Point (Map 1).

This is also indicated by a large synclinal structure between Rocky Point and Port Julia. Between Port Julia and Port Vincent different rates of subsidence adjacent to east - west faults are suggested by facies relationships of quartz sands grading to clays in the Rogue Formation (Chart 3B).

The two southern blocks (B-C) which form the lower portion of Yorke Peninsula, have undergone different rates of movement. The southernmost block C (Map 1) was a persistent high during most of the Upper Eocene as Upper Eocene sediments are not present on this block. During the Oligocene this block began to founder as remnants of Oligocene are located there. Thinner sequences of Oligocene and Miocene sediments accumulated on the landward side of north - south faults as shown by the transgressive Rogue Formation and Port Vincent Limestone. The northward component of transgression (Chart 4) during the accumulation of these beds possibly indicates greater subsidence in a direction parallel to and toward the present continental shelf; thus it would be associated with larger scale movements ("epeirogenic"). It is very likely that the St. Vincent Basin was a basin on the continental shelf during this major transgression. This is indicated by remnants near the middle of Yorke Peninsula and palaeoecological investigations of foraminifera which indicate a major change in the palaeogeography of this basin (Chart 9, Text Figs. 16 and 17).

Middle Miocene - Lower Pliocene and Pleistocene Faulting and Folding Movements

Pronounced folding and faulting of Tertiary sediments occurred on both the eastern and western sides of the basin. On the southern side of both the Willunga and Noarlunga Embayments Tertiary sediments were steeply folded (Howchin, 1911; Glaessner, 1953) while Tertiary beds show a vertical displacement greater than 1000 feet (305 m) on opposite sides of the Para Fault. Although the Willunga and Noarlunga Embayments acted like a single tectonic unit (Twidale et al., 1967), more than 300 feet (90 m) of movement occurred adjacent to the Para Fault during and after the deposition of Pliocene beds. Folded and faulted Pleistocene beds are present adjacent to the Willunga Fault-line while fanglomerates adjacent to the Eden - Burnside Fault Zone indicate Pleistocene movement of the structural high separating the Noarlunga and Adelaide Embayments. The magnitude of movement is about 1300 feet (396 m) during the Cainozoic. Pronounced faulting and folding movements were the consequence of uplift of the Mt. Lofty Ranges and downwarp of the depositional axis of the basin (Glaessner and Wade, 1958).

On the east coast of Yorke Peninsula, folding and tilting movements occurred both within the Pliocene and Pleistocene but movements in the "shield" area were not as pronounced as those on the opposite side of the Gulf. Numerous drape folds are present in this area (Glaessner, 1953b; Charts 3A, B, C and D). Immediately south of Sheoak Flat, Pliocene beds have been folded after they were deposited (Chart 3B). South of Stansbury unconformable relationships between Miocene, Pliocene and Pleistocene beds indicate a component of tilting movements in a southerly direction (Chart 3D).

In fault-controlled basinal deposition regressive phases are dependent on relative movements of fault blocks and cannot be regionally correlated without specific stratigraphic evidence.

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APPENDIX

PLATES

Plate 1

Fig. 1 Southward view in Noarlunga sand quarry illustrating (1) planar, tabular cross-strata, (2) lenticular silty clays and (3) basal truncated surface of a channel in the North Maslin Sands.

Fig. 2 An eastward view of stream channels in Noarlunga sand quarry (1) represents vertical infilling and lateral accretion northwards. Apparent section of channel (2) downcuts margins of channel (1). Finer grained sands interbedded with lenticular clays (3) are numerous above channels.

Plate 2

Fig. 1 A northward view in Noarlunga sand quarry of channel-lag deposits found in lower part of North Maslin Sands. Basal scours are very apparent below medium to fine grained sand.

Fig. 2 Planar, wedge cross-strata found in south face of Albert's sand quarry.

Plate 3

Fig. 1 Close-up view of lignite in Noarlunga sand quarry illustrating black laminated lignite and oxidized top and base.

Fig. 2 Leaf impression from oxidized level in lignite deposit found in Noarlunga sand quarry. White stip represents 1 cm.

Fig. 3 Leaves with cuticle located at base of Chinamans Gully Beds.

Plate 4

Fig. 1 South face of Noarlunga sand quarry illustrating lens of South Maslin Sands (1) unconformably overlying the fluviatile North Maslin Sands (2).

Fig. 2 Southeast view in coastal cliffs at Maslin Bay showing a small estuarine channel in South Maslin Sands.

Plate 5

Fig. 1 Undersurface of South Maslin Sand block showing greyish white calcareous sand infilling *Callianassa* burrows in grey South Maslin Sands.

Fig. 2 View of upper part of South Maslin Sand at Whitton Bluff, Noarlunga Embayment, illustrating numerous bioturbations. Grey, laminated sand is South Maslin Sands whereas salt and pepper greyish white calcareous sand infills sediment from above formation, the Tortachilla Limestone. Twenty cent coin used as scale in lower right-hand corner.

Plate 6

Fig. 1 View showing pseudo-cut-and-fill structure between quartz sands below and arenaceous bryozoal limestones above.

Fig. 2 View of fresh surface illustrating bioturbated South Maslin Sands. Ferruginous sand can be seen faintly through weathered detritus (Fig. 1). Actual contact is found between poorly-sorted sands of the Tortachilla Limestone and South Maslin Sands where burrows penetrate the South Maslin Sands.

Plate 7

Fig. 1 Southern view of Banded Marls north of Blanche Point, Willunga Embayment, showing concentration of silica into layers and nodules.

Fig. 2 Vertical view of bedding plane in bryozoal limestone (Port Willunga Beds) located at the coast on the northern side of the Willunga Embayment. Echinoid trails are shown.

Plate 8

Fig. 1 Slump structure within the Port Willunga Beds south of Sellick Beach. Small black pods are nodules of secondary silica.

Plate 8

Fig. 2 Small scale gravity thrust on lower limb of small fold south of Sellick Beach.

Fig. 3 View looking south at Sellick Beach where large truncated surfaces occur within the Port Willunga Beds. Figure at left represents scale.

PLATE 1

FIG. 1

FIG. 2

PLATE 2

FIG. 1

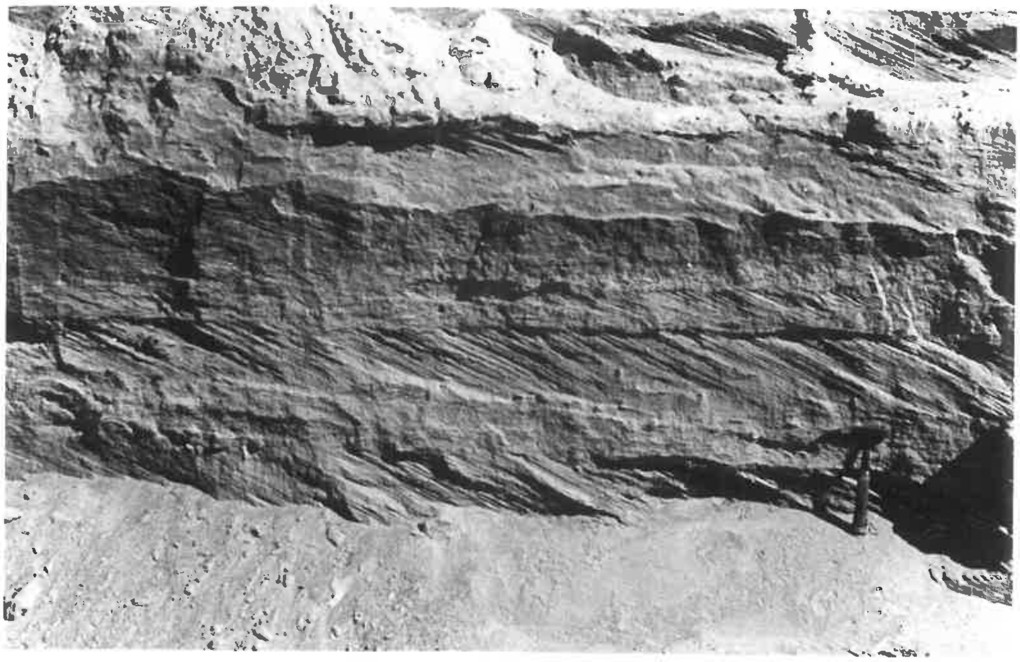

FIG. 2

PLATE 3

FIG. 1

FIG. 2

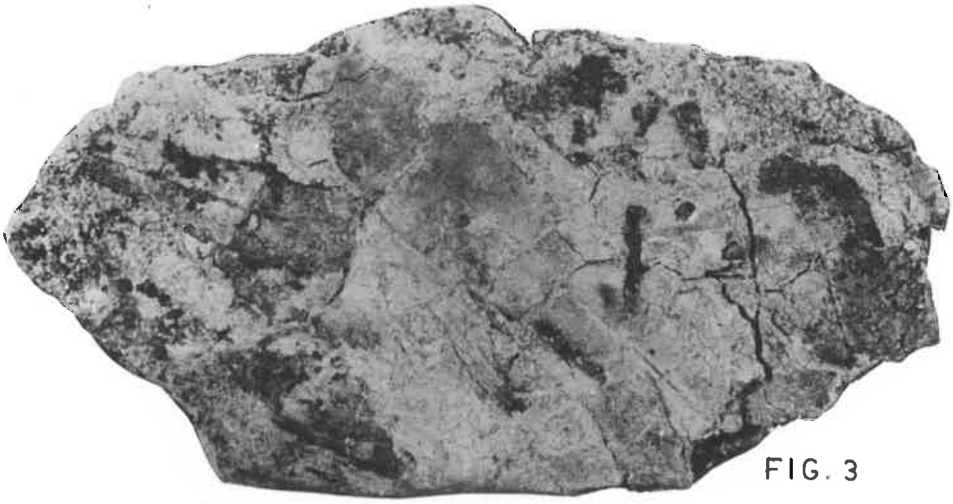

FIG. 3

PLATE 4

FIG. 1

FIG. 2

PLATE 5

FIG. 1

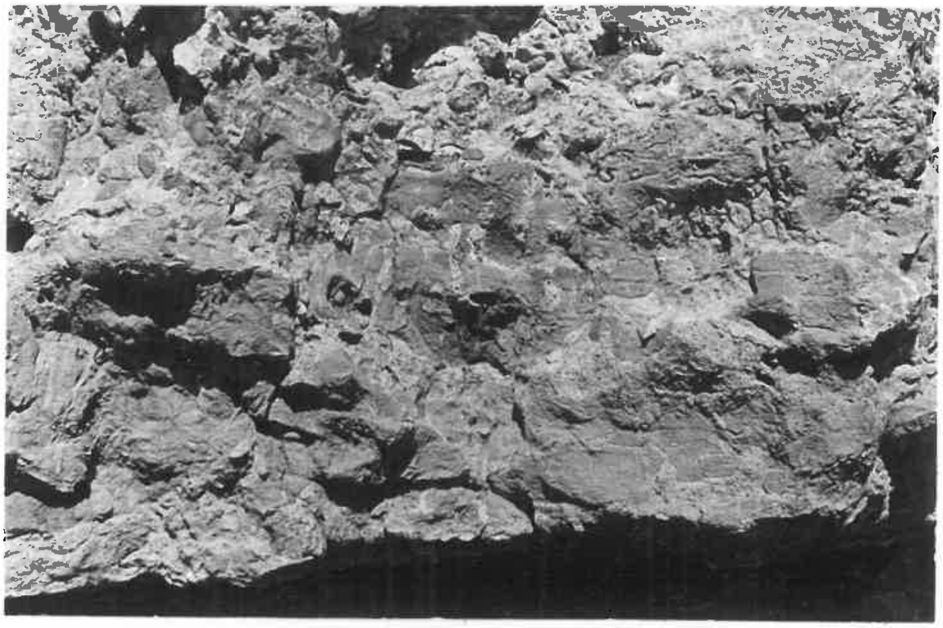

FIG. 2

PLATE 6

FIG. 1

FIG. 2

PLATE 7

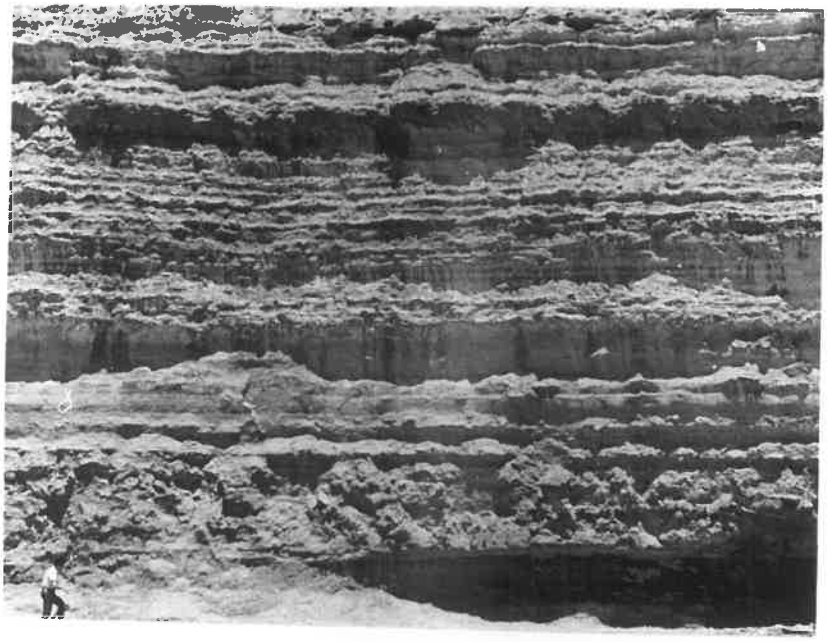

FIG. 1

FIG. 2

PLATE 8

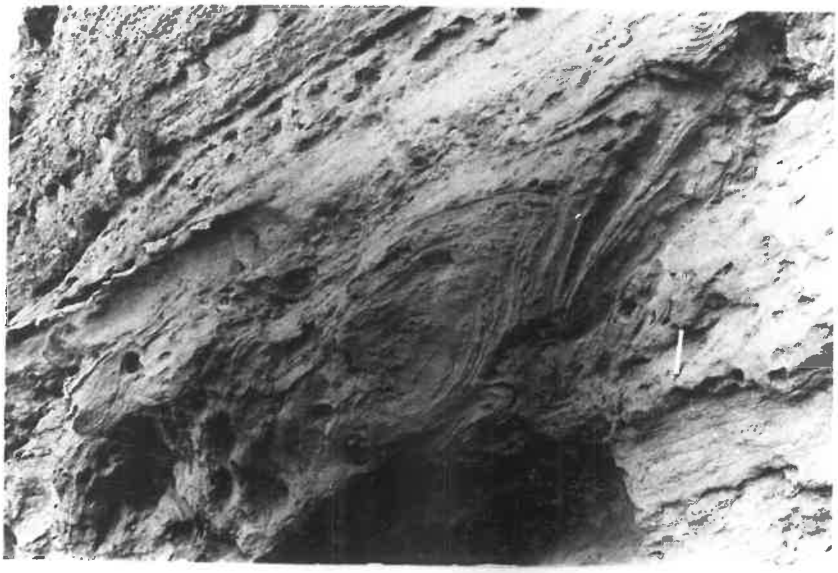

FIG. 1

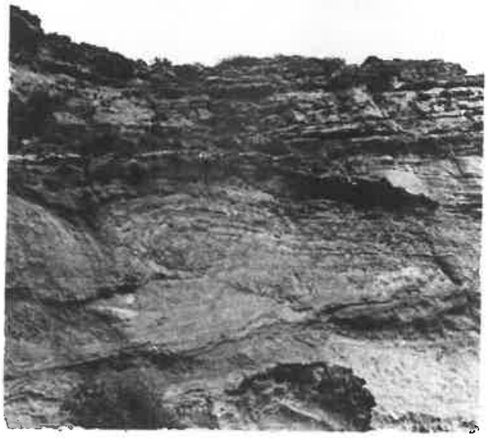

FIG. 2

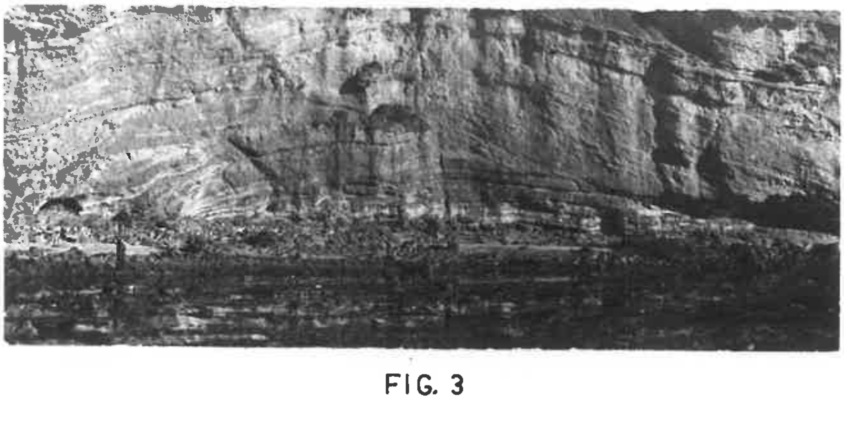

FIG. 3