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DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY

PALAEONTOLOGY SECTION

FORAMINIFERA AND STRATIGRAPHY OF THE TYPE SECTION OF PORT WILLUNGA BEDS, ALDINGA BAY

by

J.M. LINDSAY
PALAEONTOLOGIST

D.M. 584/67

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FORAMINIFERA AND STRATIGRAPHY OF THE TYPE SECTION OF PORT WILLUNGA BEDS, ALDINGA BAY *

by

J.M. LINDSAY +

SUMMARY

The type section 20 miles (32 km.) south of Adelaide has been re-examined. Comprising about 107 feet (32 m.) of bryozoal calcarenitic impure limestones, sands, silts, and clays, it is informally subdivided into three apparently conformable successions of beds, the middle interval characterized by horizons with spicular cherty nodules. Equivalents of these three intervals are present in the Willunga Bore W.B.1, and in bores in the Adelaide Plains Sub-basin. The top of the Eocene Aldingan Stage is represented by the top of a hard grey marker bed at the base of the siliceous interval about 45 feet (14 m.) above the base of the formation.

Planktonic and benthonic foraminifera indicate that the age of the section ranges from Upper Eocene to Oligocene. Four informal planktonic zones are recognized, using successive extinctions of *Turborotalia aculeata* (Jenkins), *Globigerina linaperta* (Finlay), *Chiloguembelina cubensis* (Palmer) and *Guembelitria stavensis* Bandy. These zones span Aldingan to lower Janjukian Stages, and can be related to a planktonic zonal scheme recently proposed for New Zealand.

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+ Palaeontologist, Geological Survey of South Australia

INTRODUCTION

Rocks referred to Port Willunga Beds comprise a significant part of the Tertiary sequence in the St. Vincent Basin and its sub-basins. Investigation of the type exposure of Port Willunga Beds has therefore been a necessary step towards an understanding of the place of the formation in sequences elsewhere especially in the Adelaide Plains Sub-basin.

The type of the formation at Aldinga Bay, 20 miles (32 km.) south of Adelaide (Fig. 1) forms part of the coastal exposure of the Cainezoic rocks in the Willunga Sub-basin of the St. Vincent Basin. Following interest in the sequence over a period of at least 75 years by geologists and palaeontologists, it was mapped, described, and formally sub-divided and named by Reynolds (1953). The Port Willunga Beds consist of a bryozoal calcarenitic series of variable hard and soft rocks including impure limestones, sands, silts, and clays, with an interval characterized by horizons of siliceous nodules. The beds, which are well exposed in low coastal cliffs around the central part of Aldinga Bay, have gentle southerly dips of up to 3° but are in part, slightly folded and faulted (see Fig. 2). They are now estimated to be about 107 feet (32½ m.) thick which is close to Reynolds's figure. The thin gravelly sand at the base of the formation (following Ludbrook, 1956) overlies Chinaman's Gully Beds with minor disconformity, and the formation is overlain by Pliocene Hallett Cove Sandstone with mild angular unconformity.

INSERT FIGURE 1

Fig. 1. Locality map and plan showing position of samples taken from stratotype Port Willunga Beds.

METHODS

Fig. 1 shows the localities at which samples were taken and Fig. 2 their stratigraphic positions. Included are samples from a pit dug at the site of 129-66, and also tube samples from a "Wacker" hammer hole sunk from the bottom of the pit until stopped in hard sandstone. Washed and unwashed samples and microfaunal preparations, are held in the Palaeontology Section of the Geological Survey of South Australia.

The photographs of planktonic foraminifera in Plate 1 were taken with a Leitz Laborlux microscope, using a Leitz Ultrapak lighting unit in combination with a 6.5X objective and relief condenser. Adox KB 12 film was used, and prints were made on Agfa Brovera paper.

INSERT FIGURE 2

Fig. 2. Foraminiferal log, lithology, and stratigraphy of stratotype Port Willunga Beds

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CORRELATION ACROSS ALDINGA CREEK

The exposed Port Willunga Beds are divided into a northern and a southern portion by the sand-covered and alluvium-filled entrance to Aldinga Creek, as shown in Fig. 1. In order to consider the sequence as a whole it is therefore necessary to determine the stratigraphic relationship between the northern and southern sections across the distance of more than 800 feet (244 m) which separates them. These are several reasons why this is not a simple matter. Firstly, some of the beds are observed to vary laterally in thickness and lithology. As early as 1878, Tate noted their "most diversified character-clays, limestones, and sands rapidly replacing one another in horizontal and vertical extension". Secondly, minor folding and faulting are apparent in parts of the sequence as shown in Fig. 2. It is likely that the concealed section has been affected by one or more of these factors. In addition, matching of the sections immediately north and south of Aldinga Creek is rendered more difficult by the limited thicknesses available for examination.

Glaessner (1951, p. 275), recording the measurement by Dolling in 1949 of 25 feet (7½ m.) of "polyzoal sands and clays" north of Aldinga Creek, and 97 feet (30 m.) of "polyzoal sandy marls" south of it, listed these thicknesses as consecutive and did not discuss the relationship between the two sections. Reynolds did not explicitly state the thickness of beds common to both exposed sections. In his Fig. 1, this thickness is apparently drawn as nine feet (2.7 m.). In his more detailed and definitive Fig. 2 it is shown to be little more than two feet (0.6 m.). However, in both of these representations the total thickness of the formation is 111½ feet (34 m.). Glaessner and Wade (1958) produced from these data a composite section with the same total thickness.

At the time that Ludbrook and Lindsay (1966) recorded their preliminary notes on the range of Globigerina linaperta and the extent of the Aldingan Stage within the formation, the writer accepted Reynold's correlation of beds either side of Aldinga Creek as shown in his Fig. 2. However, the ranges of Turborotalia aculeata in the northern and southern sections suggested that more of the beds than he indicated in Fig. 2 are common to the two sections.

Later in 1966, during a discussion with Mr. W. Stewart of the Geology Department, University of Adelaide, it became apparent that further measurements should be made to check the thickness common to both sections. In a brief stadia survey, several marker beds near Aldinga Creek were traced by the writer, and the results are presented slightly diagrammatically in Fig. 2. The green clay with white limy nodules, which was used as a marker bed by Reynolds and from which his sample A.211 and the writer's sample 132-66 were taken, is matched with one of the green clays north of the creek as shown. Both beds contain the uppermost occurrence of Turborotalia aculeata in their respective sections. This correlation is considered to be reasonably consistent with the lithological, structural, and microfaunal data, but it is certainly desirable that the depth to Chinaman's Gully Beds should be proved south of Aldinga Creek by drilling.

The type section of Port Willunga Beds as now re-measured, is therefore approximately 26 feet (8 m.) thick north of Aldinga Creek, and 89 feet (27 m.) thick south of it, with nearly 8 feet ($2\frac{1}{2}$ m.) of overlap between the sections, yielding a total thickness of about 107 feet ($32\frac{1}{2}$ m.).

LITHOLOGICAL UNITS

Reynolds, in his Fig. 2, distinguished 29 lithological units in the type section. His basal bed, a green fossiliferous clay, is now considered to be the top unit of Chinaman's Gully Beds. The remaining 28 units may be grouped into three lithological subdivisions which are recognizable elsewhere in the Willunga and Adelaide Plains Sub-basins. For the present, these three subdivisions are simply referred to as the lower, middle, and upper sequences, but future work may show that they merit formal stratigraphic status.

Numbering Reynolds's 28 units from the bottom up, the lower sequence contains units 1 to 12 and is by present measurement and correlation about 43 feet (13 m.) thick. It consists of a thin basal gravelly sand followed by cream cross-bedded bryozoal calcarenitic sandy limestones, calcareous sandstones and sands, green-grey clays (often with white limy nodules and fawn, brown, or pale grey, impure calcarenitic limestones, silt and marls. This variable succession extends up to the base of th first hard bed which has some siliceous cementation - the "hard consolidated grey marly bed to be seen in the caves below Port Willunga" (Reynolds, Fig. 2).

The middle sequence consists of most of the remainder of the type section, up to and including the lower part of unit 28. It is about 52 feet (16 m.) thick, and is characterized by the sporadic development of a hard spicular cherty phase typically occurring as bands of fawn and grey fossiliferous cherty nodules in softer fawn to pale grey impure limestones, silts, and marls, all calcarenitic and sandy. At the base of this interval is the hard marker bed noted above, which has some siliceous phase but is mostly limestone to calcareous siltstone and sandstone. The base of the lowest bed with prominent siliceous nodules is from 4 to 5 feet (1.2 to 1.5 m.) above the top of the marker bed. This middle, siliceous, interval in Port Willunga Beds is distinct from the older siliceous beds developed in Blanche Point Banded Marls. The two are separated by about 107 feet (32½ m.) of Blanche Point Soft Marls, Chinaman's Gully Beds and Aldingan Port Willunga Beds in the exposures at Maslin and Aldinga Bays.

The upper sequence comprises the upper part of unit 28 to the top of the exposed section. It is about 12 feet (3½ m.) thick, consisting of yellow-brown, fawn, and pale grey bryozoal beds including hard limestone bands, softer impure limestones, silty sands, and at the top of the exposure cross-bedded calcarenitic sandstones.

Reynolds did not define the top of Port Willunga Beds but simply noted that the top of the formation is not revealed in the type section. $3\frac{1}{2}$ miles ($5\frac{1}{2}$ km.) inland, the Willunga Bore W.B.1 (Glaessner and Woodard, 1956; Ludbrook, 1956; Lindsay 1966) penetrated, above the stratigraphic level of the top of the type section, more than 160 feet (49 m.) of calcareous sands, sandstones, and sandy limestones, which are evidently also Port Willunga Beds. They extend up beyond the level of Janjukian (Oligocene) beds at the top of the type section into beds which are Longfordian (Lower Miocene). The three lithological subdivisions of the type section can also be recognized in broad outline in the bore, despite changes there in lithofacies due to deposition under more marginal and restricted conditions.

Calcarenitic limestones, sands, and clay, which may be included within the scope of Port Willunga Beds are widespread in the St. Vincent Basin (Glassner and Wade, 1958). In the Adelaide Plains Sub-basin Miocene beds up to Balcombian Stage, including the Munno Para Clay Member, are known from bores (Lindsay and Shepherd, 1966) and in one locality the presence of Heterolepa victoriensis (Chapman, Parr, and Collins) suggests Bairnsdalian Stage (Lindsay, 1965). It has been recently demonstrated (Lindsay, 1967) that equivalents of the three lithological subdivisions of the type section are recognizable in deeper bores in the Adelaide Plains. The middle, siliceous, interval is well-developed at least as far north as Hundred of Dublin, but the lower interval is difficult to separate from Blanche Point Soft Marls, and Chinaman's Gully Beds usually cannot be distinguished.

The whole succession of Port Willunga Beds attains a maximum known thickness of 874 feet (267 m.) in the Croydon Bore where, in the lower part of this succession, equivalents of the type section are 440 feet (125 m.) thick.

CORRELATION WITH AUSTRALIAN AND NEW ZEALAND STAGES

After tracing the usage of the stage name Aldingan, Ludbrook and Lindsay redefined the term in the restricted time-rock sense as representing the time interval required for the deposition at Aldinga and Maslin Bays of the Tortachilla Limestone, the Blanche Point Marls, the Chinaman's Gully Beds, and the lower half of the Port Willunga Beds." The upper boundary of the stage was drawn at a level of natural subdivision, involving both an important microfaunal event - the top of the range of Globigerina linaperta - ,and an important lithological development - the commencement of the middle, siliceous, interval of Port Willunga Beds. The end of the Aldingan Stage is now further defined as being represented by the top of the hard grey marker bed which is the basal unit of the middle interval as described above. By present measurement and correlation the boundary is at approximately 45 feet (14 m.) above the base of the formation.

Raggatt and Crespin (1955), followed more recently by Carter (1964), have restricted the Janjukian Stage in a time-rock sense to represent the time interval required for the deposition of the Jan Juc Formation in the Bells Headland - Torquay area of southern Victoria. The most diagnostic planktonic event at present available to link the type sections of Jan Juc Formation and Port Willunga Beds, is the extinction of Chileguembelina cubensis which takes place near the base of the former and near the top of the latter. This event is a feature of Carter's Faunal Unit 4, in the lower episode of the Janjukian. From available data on the range of the species in both sequences it may be inferred that less than 20 feet (6 m.) of Port Willunga Beds, at the top of their type section, are early Janjukian. Most of the middle, siliceous, interval appears to be strictly pre-Janjukian and it is post-Aldingan as at present defined. Further description of the Jan Juc Formation and its planktonic foraminifera will be necessary to further clarify the relation between Aldingan and Janjukian Stages.

Comparison of the ranges of several planktonic species in Port Willunga Beds with their ranges as recorded by Jenkins for New Zealand, suggests correlation with the Kaiatan, Runangan, and Whaingaroan Stages as shown in Fig. 2.

AGE OF THE TYPE SECTION

Eocene age was recently ascribed to the lower, Aldingan, part of the type section by Ludbrook and Lindsay, the writer having recognized in it, an apparently unreworked foraminiferal succession with Globigerina linaperta and associated Eocene species. Although in earlier years considered all of Eocene age by Tate (1879, 1899) and Tate and Dennant (1896), the type section was more recently considered to be of Oligocene to Lower Miocene age. The foraminiferal evidence now available suggests an Oligocene age for the post-Aldingan part of the section.

PLANKTONIC ZONES

Lithologies and microfaunas suggest that stratotype Port Willunga Beds, as indeed most of the marine Tertiary of the St. Vincent Basin, were deposited under conditions of somewhat restricted access to the open ocean. This environment does not favour the presence of the tropical or temperate planktonic foraminifera which have been chosen to diagnose planktonic zones in standard sequences of comparable age elsewhere. For example, of the zonal species of Blow and Banner (1962), only _Globigerina ampliapertura_ Bolli has been found. Zonal species of Jenkins (1965) not yet encountered include _Globorotalia inconspicua_ Howe, and _Globigerina brevis_ Jenkins. _Globigerapsis index index_ (Finlay), key species of the _index_ zone or zone 2 of Carter (1964, p. 46) followed by Wade (1964), occurs only very rarely and immaturely. _Globigerina angiporoides angiporoides_ Hornibrook, another of Jenkins's zonal species, although very rare is typical and persistent within the range of _G. linaperta_ s.str. Above this however, only occasional doubtful specimens are present at the level of the _angiporoides angiporoides_ zone in New Zealand, and the zone is thus not suitable for local use. _G. euapertura_ Jenkins is present but not well-developed in the type section. Jenkins,however, defined the lower boundary of his _euapertura_ zone by the extinction of G. _angiporoides angiporoides_, and as noted above this is not a suitable criterion at Aldinga Bay.

The _linaperta_ zone of Carter (1964) followed by Wade (1964), was equated by them with Carter's Faunal Unit 3, which is characterised by the microfauna of the upper part of the Castle Cove Limestone, and the "Lower Glen Aire Clays", containing "a form of _Globigerina linaperta_ with swollen chambers" (Carter 1958, p. 21). Examination of available material leaves little doubt that this is _G. angiporoides angiporoides_, and not _G. linaperta_ _s.str_. Jenkins records similar upward ranges for both _G. linaperta_ and _Globigerapsis index index_ in New Zealand. Faunal Unit 3, or the "_linaperta_ zone" in this sense, has not been used in the present study due to some uncertainty as to the planktonic content and stratigraphic position of the beds used to define it.

Jenkins defined a different zone of G. linaperta in the Upper Eocene of New Zealand, between the extinction of Globorotalia inconspicua and the initial appearance of Globigerina brevis. Neither of these species is known from Port Willunga Beds but his zone is adapted for local use as described below.

The most useful characteristic of Carter's Faunal Unit 4, the final appearance of Chiloguembelina cubensis, is utilized as the upper limit of a zone of C. cubensis which follows the zone of G. linaperta. Guembelitria stavensis is associated with C. cubensis at the level of Faunal Unit 4 and ranges a little higher. This relationship is used to define a zone of G. stavensis, which occurs at the top of the type section.

Despite their usefulness at a certain stage in the development of Australian Tertiary stratigraphy, Carter's Faunal Units or Zones are for various reasons, proving unsuitable or difficult to use (at least in the Eocene and Oligocene) as a framework for planktonic zonation. The recent work of Jenkins in New Zealand has provided the basis for an alternative approach and it is therefore proposed to define from stratotype Port Willunga Beds, informal local planktonic zones which may be useful within the St. Vincent Basin, and may also be related to zones elsewhere via more diverse planktonic sequences from southern Australian and New Zealand.

The lowest such zone in the type section is that of Turborotalia aculeata (= Globorotalia inconspicus aculeata Jenkins) which extends below Port Willunga Beds, and whose upper limit is marked by the top of the range of the species. Jenkins recorded the same extinction level for both of the forms he regarded as subspecies of _G. inconspicua_. If _T. aculeata_ has a similar range in South Australia, the basal 22 feet (6.7 m.) of Port Willunga Beds containing the species, correlate with part of the Kaiatan Stage of New Zealand at the top of the zone of _G. inconspicua_. Species associated with _T. aculeata_ in the _aculeata_ zone at Aldinga Bay include _Globigerapsis index index_, _Globigerina linaperta_, _G. angiporoides angiporoides_, _G. ampliapertura_, _Turborotalia increbescens_ (Bandy), _Chiloguembelina cubensis_, and _Cassigerinella_ sp. cf. _C. chipolensis_ (Cushman and Ponton.) Below Port Willunga Beds, the sequence at Aldinga and Maslin Bays is not at present known to have other planktonic events suitable as a basis of zonation until _Hantkenina alabamensis compressa_ Parr is encountered in the lower part of Blanche Point Transitional Marls.

A zone of _Globigerina linaperta_ has its lower boundary defined by the top of the range of _Turborotalia aculeata_ and its upper by the top of the range of _G. linaperta_ s.str. This is comparable with the _G. linaperta_ zone of Jenkins in the upper Kaiatan and Runangan of New Zealand, but there he shows the final appearance of _G. linaperta_ to be contained within the basal part of his _brevis_ zone which is not yet recognised in Australia. Species associated with _G. linaperta_ in this adapted _linaperta_ zone include _Chiloguembelina cubensis_, _Cassigerinella_ sp. cf. _C. chipolensis_, _Turborotalia increbescens_, _Globigerina ampliapertura_, _G. angiporoides angiporoides_, and, at the top, _Guembelitria stavensis_ and _Globigerina suapertura_. The zone of _G. linaperta_ is present in the uppermost part of the Aldingan.

The zone of _Chiloguembelina cubensis_ has its lower boundary defined by the top of the range of _G. linaperta_ and its upper boundary by the final appearance of _C. cubensis_. Species associated with the zonal species include *Guembelitria stavensis*, *Cassigerinella chipolensis*, *Globigerina euapertura*, and very rare and doubtful specimens of *G. angiporoides angiporoides*. Also occurring towards the top of the zone in the type section are *Globigerina bulloides* d'Orbigny, *G.* sp. cf. *G. ciperoensis ciperoensis* Bolli, *G. labiacrassata* Jenkins, and *Globorotaloides testarugosa* (Jenkins). A specimen of *Globanomalina* sp. cf. *G. naguewichiensis* Myatliuk was recovered from the top of the zone. The zone of *C. cubensis* is post-Aldingan, and its uppermost part, at least, is early Janjukian. The zone is likely to be synchronous with most of the *brevis* zone, the whole of the *angiporoides angiporoides* zone, and the basal part of the *euapertura* zone of Jenkins.

The zone of *Guembelitria stavensis* has its lower boundary defined by the top of the range of *Chiloguembelina cubensis*, and its upper boundary by the final appearance of the zonal species, the latter event almost certainly occurring stratigraphically higher than the top of the type section of Port Willunga Beds. In the Willunga Bore W.B.1, and generally in the Adelaide Plains Sub-basin, *G. stavensis* ranges up above *C. cubensis* (Lindsay 1966, 1967, cited above). At the top of the type section the zonal species is associated with *Cassigerinella chipolensis* and *Globigerina bulloides*. The zone would no doubt occupy an interval in the lower part of Jenkins's *euapertura* zone (though Jenkins does not record *G. stavensis*), in uppermost Whaingaroan and perhaps basal Duntroonian..

FORAMINIFERA

Planktonic species

Throughout the type section, planktonic species are mostly small and restricted in variety, although at times abundant. No reworking is apparent. The local ranges of more significant species are plotted in Fig. 2.

Globigerina praebulloides (many comparable with subsp. leroyi Blow and Banner), G. angustiumbilicata Bolli, G. officinalis Subbotina, and G. ouachitaensis Howe and Wallace range through the sequence, comprising an association of small, apparently tolerant, species related to the Globigerina bulloides Lineage which was discussed by Wade. They often form the most obvious and abundant planktonic component of the samples examined and appear to be typically present in Upper Eocene and Oligocene sequences elsewhere. Because of their long ranges, however, they are omitted from Fig. 2.

Guembelitria stavensis Bandy, 1949

pl. 1 fig. 1

The South Australian species of Guembelitria which occurs in the uppermost Eocene and Oligocene, has been compared with the types of G. stavensis kindly loaned by the University of Indiana. At Port Willunga, the species commences its range about 7 feet (2 m.) below the extinction of Globigerina linaperta and continues up to the top of the section beyond the highest occurrence of Chiloguembelina cubensis, this latter part of its range comprising the basal part of the zone of G. stavensis. The species has a wide distribution in the St. Vincent, Murray, and Otway Basins.

Chiloguembelina cubensis (Palmer, 1934)

pl. 1 figs. 2-3

Beckmann (1957) commented on the stratigraphic usefulness of Chiloguembelina, particularly in samples containing mainly a benthonic fauna, and his remarks are supported by the writer's experience of both Chiloguembelina and Guembelitria in the Upper Eocene and Oligocene of the Murray and St. Vincent Basins in South Australia.

Reynolds (p. 129) was the first to note the presence of "Gumbelina" in type Port Willunga Beds, from sample A.114, 18 feet above the base of the formation (Carter, 1958, p. 25). It is now known that C. cubensis ranges almost throughout the section, appearing to approach extinction towards the top, in basal Janjukian equivalents, where it becomes very rare and sporadic. The last-appearing specimen is figured.

Besides Carter's record of the last appearance of the species in Faunal Unit 4 low in the Jan Juc Formation at Bell's Headland (Carter 1964, p. 42, fig. 14), Taylor (1966), records C. cubensis above G. linaperta from Esso Gippsland Shelf No. 1 Well in his Zonule J which he compares with Faunal Unit 4. Jenkins puts the extinction of C. cubensis within the basal part of his euapertura zone, high in the Whaingaroan of New Zealand. He has recently (1966) made this extinction the eleventh in a series of twenty-nine homotaxial datum planes chosen by him for the Pacific and Trinidad Tertiary. In Trinidad, C. cubensis makes its final appearance in the opima opima zone. The occurrence of this datum plane near the top of stratotype Port Willunga Beds is thus of considerable importance. Although the planes are described by Jenkins as homotaxial and not necessarily isochronous, he accepts the extinction of C. cubensis as an Oligocene event.

Globanomalina sp. cf. G. naguewichiensis (Myatliuk, 1950)

pl. 1 figs. 4-5

A solitary small planispiral specimen with six chambers in the final whorl was recovered from the top of the cubensis zone. It is Globanomalina, apparently less akin to G. micra (Cole) than to G. naguewichiensis (fide Ellis and Messina, 1940 et seq.). The extinction of Myatliuk's species, as the last-surviving species of Globanomalina, marks the lower boundary of the basal Neogene zone N.1 of Banner and Blow (1965). Too much importance cannot be attached to a single specimen, but the occurrence does provide some support for the widely-held view that the extinetion of C. cubensis occurred in the Palaeogene and Oligocene.

Cassigerinella chipolensis (Cushman and Ponton, 1932)

pl. 1 fig. 6

Specimens with well-developed biserial enrolling and prominent aperture, occur through the cubensis and stavensis zones. The species ranges as high as the Balcombian Munno Para Clay in the Adelaide Plains Sub-basin, and up to Bairnsdalian Pata Limestone in the Murray Basin of South Australia.

Cassigerinella sp. cf. C. chipolensis

pl. 1 figs. 7-9

Blow and Banner did not find any forms referable to the genus Cassigerinella in the Eocene of the Lindi area, Tanganyika. However in stratotype Port Willunga Beds, forms from the upper part of the aculeata zone, and the linaperta zone, are referable to Cassigerinella and are compared with C. chipolensis. Eleven such specimens have been recovered. They usually have a distinct planispiral early stage, but also display the biserial enrolling of Cassigerinella. In some examples the aperture tends to be more restricted and slit-like than is the case with C. chipolensis, but the earliest form (pl. 1, figs. 7-8) has a distinctly open oval aperture. The lowest sample south of Aldinga Creek with C. sp. cf. C. chipolensis (153-66) also contains immature but characteristic Globigerapsis index index besides Turborotalia aculeata. The earliest C. sp. cf. C. chipolensis in the type section is from sample 123-66 north of Aldinga Creek, and is associated with the latest Haslinella chapmani Glaessner and Wade. Todd (1966, p. 14) has recently discussed the possibility that Cassigerinella occurs in the Eocene. The evidence from Port Willunga Beds seems to confirm that it does.

Turborotalia aculeata (Jenkins, 1965)

pl. 1 figs. 10-11

This distinctive, finely spinose Turborotalia, described from the Bortonian and Kaiatan Stages of New Zealand, is present, at times abundantly, in the basal 22 feet (6.7 m.) of the type section, in the aculeata zone. Its differences from Globorotalia inconspicua Howe, noted by Jenkins, appear to suffice for its transfer from a subspecies of G. inconspicua to a distinct species in Turborotalia. Both north and south of Aldinga Creek, the highest occurrence of T. aculeata is in a green clay with white limy nodules, supporting the equivalence of these two beds as shown in Fig. 2. The species is known from the Eocene of the St. Vincent, Murray, and Otway Basins of southern Australia.

Turborotalia increbescens (Bandy, 1949)

pl. 1 fig. 12

The species has been found only in two samples straddling the top of the *aculeata* zone north of Aldinga Creek. This is somewhat higher than the range recorded by Jenkins from New Zealand, but is within the lower part of the range recorded by Blow and Banner from Lindi (op. cit., Fig. 20).

Turborotalia opima continuosa (Blow, 1959)

pl. 1 figs. 13-14

Only two examples have been recognised, both from sample 145-66 at the top of the *[illegible]* zone, from a level near the bottom of the range of the species as recorded for New Zealand by Jenkins. The specimen figured agrees closely with Blow's diagnosis of the subspecies. Jenkins has given the subspecies full specific rank.

Globigerina ampliapertura Bolli, 1957

pl. 1 fig. 17

The species has been seen only in the Aldinga portion of the type section, mostly in the *linaperta* zone, where it is small with a relatively high arched aperture. This is comparable with the basal part of the range of the species in New Zealand as recorded by Jenkins.

Globigerina angiporoides angiporoides Hornibrook, 1965

pl. 1 fig. 25

Through the aculeata zone this form occurs typically and consistently but mostly very rarely. It ranges into the linaperta zone and occasional doubtful examples are present nearly to the top of the cubensis zone. Taylor (op. cit) recorded this species (as G. angipora Stache) only from his Zonule K of uppermost Eocene age in Esso Gippsland Shelf No. 1 Well, associated with G. linaperta. G. angiporoides angiporoides is abundant in the "Lower Glen Aire Clays", and as was noted above, there is little doubt that it is the form referred to by Carter as "G. linaperta with swollen chambers", the characteristic species of his Faunal Unit 3 or "linaperta zone."

Globigerina bulloides d'Orbigny, 1826

pl. 1 fig. 16

There has been some disagreement among micropalaeontologists over the age of earliest G. bulloides, varying for example from middle Miocene (Blow, 1959, p. 175) to Upper Eocene (Wade, op. cit., p. 278). Jenkins recorded earliest G. bulloides in New Zealand from middle Whaingaroan Stage (Oligocene), and comparable with this, in type Port Willunga Beds, forms attributable to G. bulloides enter high in the cubensis zone and are prominent within the Janjukian interval.

Globigerina sp. cf. G. ciperoensis ciperoensis Bolli, 1957

pl. 1 fig. 18

At a similar level to that recorded by Jenkins for New Zealand, the ciperoensis form is emerging as an offshoot from the

G. angustiumbilicata population at the top of the cubensis zone in Port Willunga Beds, as it develops a more highly trochospiral, five-chambered whorl, a slightly hispid test, and a more open centrally-situated umbilical aperture tending to lose its lip. The specimen most similar to G. ciperoensis ciperoensis is figured, but its umbilicus is still relatively small, and an apertural lip is still slightly developed.

Globigerina euapertura Jenkins, 1960

pl. 1 fig. 15

Commencing its range near the top of the Aldingan, G. euapertura occurs most frequently in the Janjukian interval. The rather low, rimmed, widely-arched aperture and depressed final chamber, are distinctive features. Blow and Banner discussed euapertura as a subspecies of G. ampliapertura, and showed its emergence from that lineage near the top of their turritilina turritilina zone (uppermost Eocene) at Lindi. Similarly in New Zealand, Jenkins records the commencement of the range of G. euapertura near the Runangan-Whaingaroan boundary At Port Willunga, sample 147-66 from just below the top of the Aldingan Stage contained the specimens figured of the earliest definite G. euapertura and the latest G. ampliapertura seen.

Globigerina labiacrassata Jenkins, 1965

pl. 1 figs. 20-22

A few examples of the species have been recovered from samples 9-67 and 13-67 in the upper part of the cubensis zone, at a level equivalent to the middle of its range in New Zealand. The forms have moderately thickened apertural rims, and variable size and height of aperture, as comparèd with the more typical figured specimen from the Otway Basin.

<u>Globigerina linaperta</u> Finlay, 1939

pl. 1 figs. 23-24

The apparent environmental tolerance of this species makes it stratigraphically important in Eocene correlation. Blow and Banner demonstrated its extinction at Lindi at the top of their <u>turritilina turritilina</u> zone, in beds still Eocene on the evidence of diagnostic larger foraminifera such as <u>Discocyclina</u> sp. For New Zealand, Jenkins recorded both <u>G. linaperta</u> and <u>Globigerapsis index index</u> as having become extinct at the top of the Runangan, and accepted this as the Eocene-Oligocene boundary. McTavish (1966, p. 16) maintained that <u>G. linaperta</u> "persisted into the Oligocene in Australia", while acknowledging its general extinction at the close of the Eocene. However it seems likely from present studies that Australian records of <u>G. linaperta</u> from the Oligocene refer either to <u>G. angiporoides angiporoides</u> or to forms not conspecific with <u>G. linaperta</u> but comparable with it in some aspects. The specimens figured from Port Willunga Beds show the diagnostic features of the species, and in particular the specimen from sample 148-66, the uppermost recovered, is very comparable with New Zealand material examined.

<u>Globorotaloides testarugosa</u> (Jenkins, 1960)

pl. 1 fig. 26

Good examples are present very rarely at the top of the <u>cubensis</u> zone, equivalent to the middle of the range recorded by Jenkins from New Zealand. He described the species from the base of the Lakes Entrance Oil Shaft in Victoria at the top of its range. The form has also been recorded by Taylor (op. cit.) from Esso Gippsland Shelf No. 1 Well. The figured specimen shows the characteristic coarsely pitted wall and relatively straight tangential sutures on the spiral side.

Globigerapsis index index (Finlay, 1939)

pl. 1 fig. 19

Immature examples with wide single apertures, as shown in the figured specimen, occur very rarely within the aculeata zone. Jenkins does not record Globigerapsis tropicalis Blow and Banner from New Zealand and ranges both G. index index and Globigerina linaperta to the top of the Runangan. G. index index is evidently more affected by adverse environment than is G. linaperta and its usability as a zonal indicator is thereby lessened. However, its occasional presence within the bottom 16 feet (5 m.) of the type section of Port Willunga Beds confirms the Upper Eocene age of this interval.

Benthonic species

The benthonic foraminifera have not been studied in detail and many of the species are as yet undescribed. A few of more immediate stratigraphic significance will be noted here.

An interesting assemblage is present as a numerically minor constituent of the microfauna in the basal 20 feet (6 m.) of the type section, within the Upper Eocene aculeata zone. The members of this assemblage are: Crespinina kingscotensis Wade, Linderina sp., Halkyardia sp. cf. H. bartrumi Parr, Maslinella chapmani Glaessner and Wade, Reussella finlayi Dorreen, and a genus close to Bolivinella. Their ranges within the type section are plotted in Fig. 2.

All South Australian specimens of Crespinina kingscotensis recorded by Wade in her description of the species (1955), came from Eocene beds. It has in addition been recorded by Ludbrook from Buccleuch A and B in the Murray Basin (1961,

Table X), and at Aldinga Bay (1956, p. 17) from as high as basal Port Willunga Beds. In South Australia it is thus only known as an Eocene species.

Linderina sp., and *Halkyardia* sp. cf. *H. bartrumi*, have been recorded by Ludbrook, and the latter figured, from Buccleuch A (1961). She has also noted them (1963, pp. 8, 9) from other calcareous sediments in the Upper Eocene of South Australia.

Maslinella chapmani is only known from the Eocene. Glaessner and Wade (1959) described South Australian occurrences from Upper Eocene beds at Maslin Bay, Port Noarlunga, Kingscote (Kangaroo Island) and Moorlands. Ludbrook noted the species from Buccleuch A in the Murray Basin (1961), and in 1963, in Middle and Upper Eocene microfaunas from South Australia, including the Eucla Basin. A few examples have now been recovered from the *aculeata* zone in type Port Willunga Beds north of Aldinga Creek.

A genus closely related to *Bolivinella* was recorded and figured by Ludbrook (1961) from Upper Eocene Buccleuch A in the Murray Basin, and noted by her (p. 86) to occur associated with *Hantkenina alabamensis compressa* in Blanche Point Transitional Marls at Maslin Bay. A few glauconitic internal casts of the form have now also been found at the top of Chinaman's Gully Beds in sample 118-66, and typical examples occur low in Port Willunga Beds. In a few of the specimens some coiling of the initial chambers has been observed. This species is only known from the Eocene of South Australia.

As with the planktonics, these benthonics do not appear to have been reworked from older beds. Occasional specimens show slight wear, interpreted as due to the kind of contemporaneous abrasion which might be expected in beds such as the basal cross-bedded Bryozoal sands.

The assemblage noted above thus supports the planktonic evidence for an assignment of Upper Eocene age to the *aculeata* zone in type Port Willunga beds.

Cibicides pseudoconvexus Parr, 1938, ranges throughout the section but occurs only occasionally above the *aculeata* zone, the uppermost example being found at the top of the *cubensis* zone. The species was reported by Carter to be present as high as Faunal Unit 4 (1958, Table 5; 1964, Table 3).

Although miliolids are scarce in the type section, a single good example of *Massilina torquayensis* (Chapman, 1922), was found at the top of the *cubensis* zone, within the Janjukian interval. A comparable finely striate siliceous internal cast was recovered from low in the *cubensis* zone. This is a characteristic species of the Jan Juc Formation and its South Australian correlatives. A specimen from the Ettrick Formation has been figured by Ludbrook (1961, Pl. II, Fig. 5).

Placed for the present in *Notorotalia*, a species which is probably new appears in the Janjukian near the top of the *cubensis* zone. It ranges up into the *stavensis* zone, and elsewhere into the basal Miocene of the Murray and St. Vincent Basins. More robust, and somewhat larger than *Notorotalia howchini* (Chapman, Parr and Collins), it has a more or less prominent but flush umbilical plug. It is quite distinct from *Porosorotalia crassimura* (Carter), which is present throughout the type section.

Pseudopolymorphina mutila parri Cushman and Ozawa, 1930, has only been seen from the top of the *cubensis* zone.

It was described from the Jan Juc Formation and occurs sparsely in Janjukian correlatives in the Murray and St. Vincent Basins.

Sherbornina atkinsoni Chapman occurs throughout the type section, preferring calcareous sandy facies, but S. cuneimarginata Wade is not present.

Notably absent from even the Upper Eocene part of Port Willunga Beds are Asterigerinella adelaidensis (Howchin) and a distinctive, striate, Pseudopolymorphina sp. (of Ludbrook, 1961, Pl. 1, Fig. 1). In the St. Vincent Basin the former is not known from above Blanche Point Marls and the latter ranges no higher than the Blanche Point Transitional Marls Member.

Victoriella conoidea (Rutten) has not been seen in the type section, and in any case use of the Victoriella conoidea zone (Carter, op. cit.; "V. plecte" zone of Glaessner, op. cit.) would be inappropriate for a scheme of planktonic zonation. The cubensis and stavensis zones of the present scheme are used instead for all but the uppermost part of the zone of Victoriella conoidea. The species has been found by the writer recently for the first time in the Adelaide Plains in the Croydon Bore where it occurs in Port Willunga Beds at 1,040-1,045 feet (317-319 m.) in pale brownish-grey limestone, 25 feet (7.6 m.) above the top of the stavensis zone, and associated in an upper Janjukian microfauna with Cibicides pseudoconvexus, Globigerina sp. cf. G. angulisuturalis Bolli, Massilina torquayensis, Sherbornina atkinsoni and Sherbornina cuneimarginata. This is above the level of the type section of Port Willunga Beds, and must be close to the Oligocene-Miocene boundary.

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EXPLANATION OF PLATE

PLATE 1

(All figures X 110)

All from type section of Port Willunga Beds except fig. 22.

1 Guembelitria stavensis Bandy

Hypotype Ff419, sample 145-66, top of cubensis zone, Oligocene.

2-3 Chiloguembelina cubensis (Palmer)

Hypotype Ff420, sample 145-66, as above.

2. Side view 3. Oblique view showing aperture.

4-5 Globanomalina sp. cf. G. naguewichiensis (Myatliuk)

Hypotype Ff421, sample 145-66, as above.

4. Side view 5. Apertural view.

6 Cassigerinella chipolensis (Cushman and Ponton)

Hypotype. Ff422, sample 144-66, high in cubensis zone, Oligocene. Side view, showing aperture.

7-9 Cassigerinella sp. cf. C. chipolensis (Cushman and Ponton)

7, 8. Hypotype Ff423, sample 123-66, aculeata zone, Upper Eocene.

7. Apertural side view 8, Oblique apertural view.

9. Hypotype Ff424, sample 126-66, top of aculeata zone, Upper Eocene. Side view.

10-11 Turborotalia aculeata (Jenkins)

Hypotype Ff425, sample 163-66, aculeata zone, Upper Eocene. 10. Umbilical view 11. Spiral view.

12 Turborotalia increbescens (Bandy)

Hypotype Ff426, sample 127-66, basal linaperta zone, Upper Eocene. Umbilical view.

13-14 Turborotalia opima continuosa (Blow)

Hypotype Ff427, sample 145-66, top of cubensis zone, Oligocene. 13. Side view showing the "comma-shaped aperture" noted by Blow 14. Umbilical view.

15 Globigerina euapertura Jenkins

Hypotype Ff428, sample 147-66, near top of linaperta zone, uppermost Eocene. Umbilical view.

16 Globigerina bulloides d'Orbigny

Hypotype Ff429, sample 145-66, top of cubensis zone, Oligocene. Umbilical view.

17 Globigerina ampliapertura Bolli

Hypotype Ff430, sample 147-66, near top of linaperta zone, uppermost Eocene. Umbilical view.

18 Globigerina sp. cf. G. ciperoensis ciperoensis Bolli

Hypotype Ff431, sample 145-66, top of cubensis zone, Oligocene. Umbilical view.

19 Globigerapsis index index (Finlay)

Hypotype Ff432, sample 161-66, aculeata zone, Upper Eocene. Umbilical view showing single aperture of immature specimen.

20-22 Globigerina labiacrassata Jenkins

20. Hypotype Ff433, sample 9-67, high in cubensis zone, Oligocene. Umbilical view showing relatively small aperture with thick rim.

21. Hypotype Ff434, sample 13-67, cubensis zone, Oligocene. Umbilical view showing larger aperture and thick rim.

22. Hypotype Ff435, Oil Development N.L. Mount Salt Structure Hole No. 3, 560-570 feet, Gambier Limestone, Oligocene, Otway Basin, 10 miles (16 km.) south-west of Mount Gambier. Umbilical view showing typical apertural features.

23-24 *Globigerina linaperta* Finlay

23. Hypotype Pf436, sample 120-66, *Aculeata* zone, Upper Eocene. Umbilical view.

24. Hypotype Pf437, sample 148-66, top of *linaperta* zone, uppermost Eocene. Umbilical view.

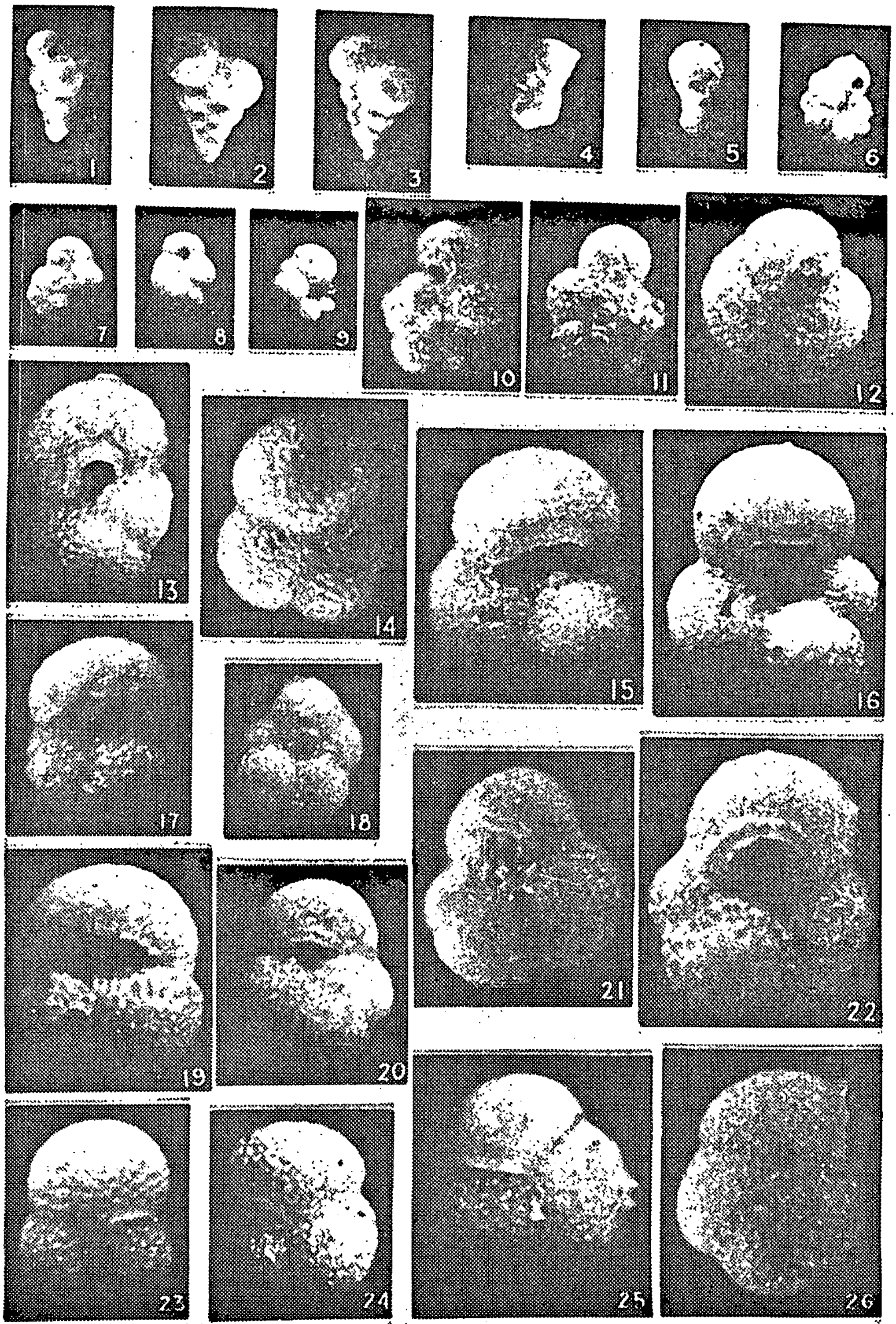
25 *Globigerina angiporoides angiporoides* Hornibrook

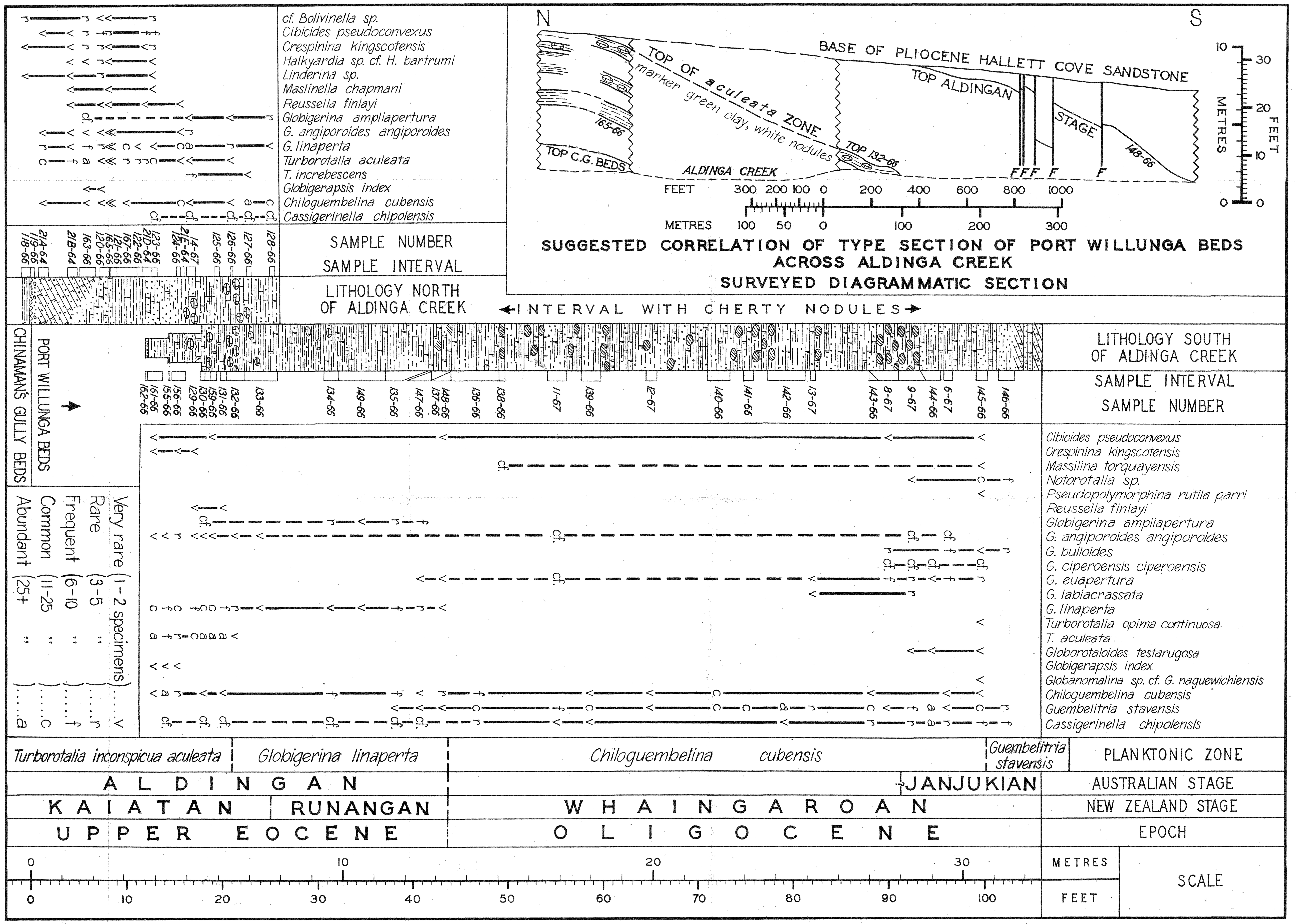
Hypotype Pf438, sample 212-64, high in *aculeata* zone, Upper Eocene.

26 *Globorotaloides testarugosa* (Jenkins)

Hypotype Pf439, sample 145-66, top of *[illegible]* zone, Oligocene. Spiral view.

PLATE 1





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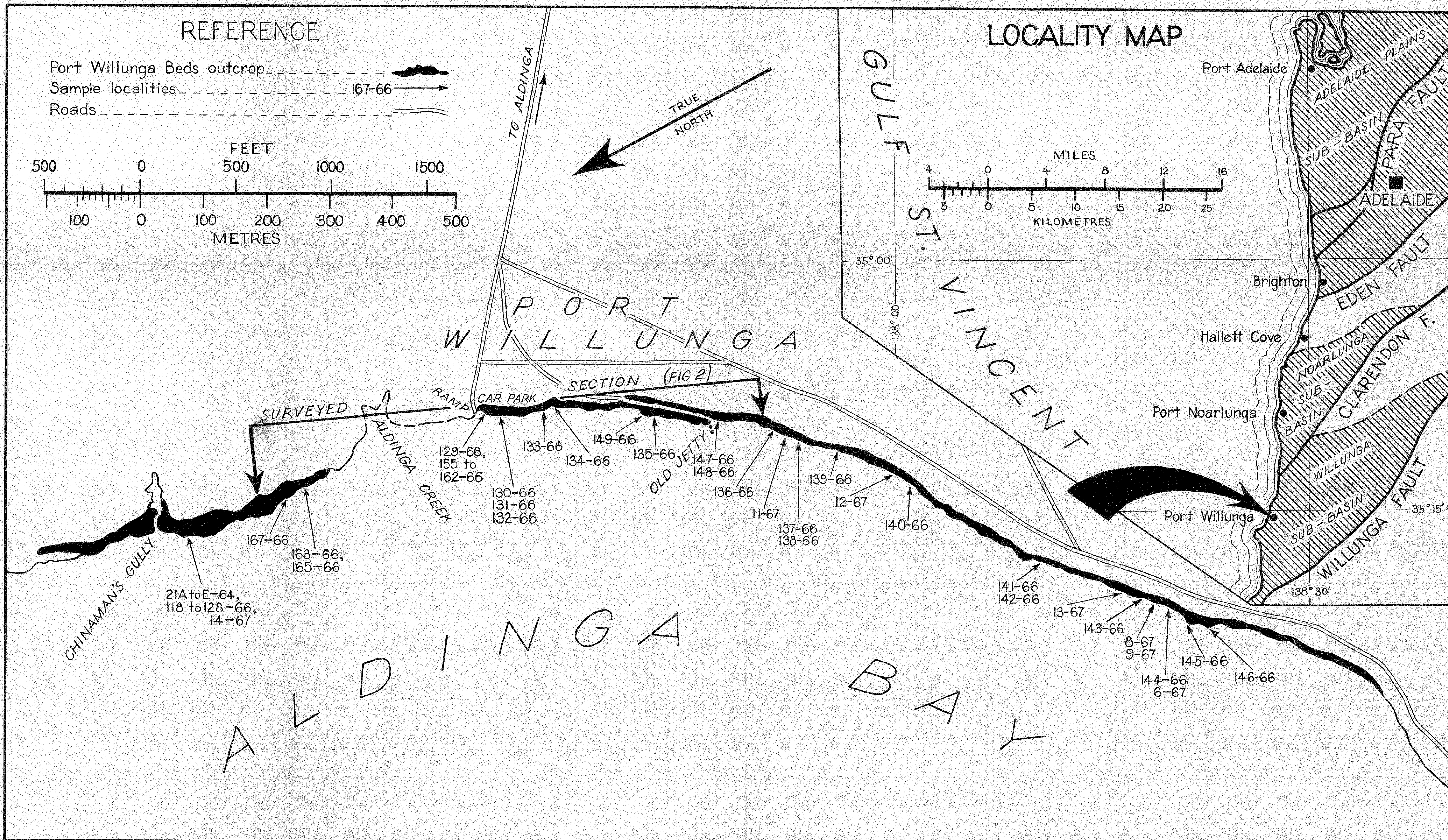

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Fig.1. Type Section of Port Willunga Beds, locality map and plan showing positions of samples taken.

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