Geological Survey of Victoria

LATE EOCENE AND THE EOCENE/ OLIGOCENE BOUNDARY IN THE AIRE DISTRICT, VICTORIA

C. ABELE

UNPUBLISHED REPORT 1994/7

DEPARTMENT OF ENERGY AND MINERALS

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CONTENTS

SUMMARY

The Eocene-Oligocene transition is represented in marine strata in the coastal Aire district in southwestern Victoria. The last appearance of the planktonic foraminifer *Globigerinatheka index* (rare, sporadic specimens excepted) at or near the top of the Castle Cove Limestone in the Castle Cove section is the best approximation to the Eocene/Oligocene boundary. Outcrops of Browns Creek Clay and Castle Cove Limestone between the mouths of Browns Creek and Johanna River are Eocene, below the last appearance of *G.index*. A horizon in the Browns Creek section has been correlated with the Chinaman Gully regression in the St Vincent Basin in South Australia. Either the correlation is incorrect or the regression took place well before the extinction of *G.index* near the end of the Eocene.

INTRODUCTION

The main aim of this report is to document and discuss data relevant to Late Eocene stratigraphy and the recognition of the Eocene/Oligocene boundary in the Aire district in Victoria. Current controversy about the location of this boundary in outcrop sections near the mouth of Browns Creek has provided the major motive for this work.

In southeastern Australia, the Eocene-Oligocene transition is represented in marine strata outcropping along the coast in two areas - in the Aire district (eastern Otway Basin) in Victoria and near Port Willunga (St Vincent Basin) in South Australia (Fig. 1). The Eocene-Oligocene age of the beds has been accepted for more than 40 years, after Parr's (1947, and in Glaessner, 1951) identification of the foraminifer *Hantkenina* from the lower parts of both sections indicated Late Eocene. The precise placement of the Eocene/Oligocene boundary, however, is still controversial.

In the past, part of the difficulty lay in the lack of a commonly accepted, precisely defined Eocene/Oligocene boundary in Europe, where the Eocene was named from the Paris and London basins by Lyell (1833), and the Oligocene from northern Germany by Beyrich (1854). However, the boundary has been generally recognised in terms of intercontinental planktonic foraminiferal zones defined from low latitudes - either at the top of the *Turborotalia cerroazulensis* s.l. Zone, corresponding to a level in the upper part of Zone P 17, or at the P 17/P 18 zone boundary.

Recently the Eocene/Oligocene boundary has been stratotypified in the Massignano section (Umbro-Marche Apennines), near Ancona, Italy. The boundary point was designated at the 19 m level within Chronozone C 13 R; this is 0.14 of the stratigraphic distance below the base of Chronozone C 13 N (= C 13 R.14). It corresponds to the extinction level of *Hantkenina* and its relatives, recommended to mark the P 17/P 18 zone boundary, and an age of 34 Ma (Nocchi et al., 1986; Premoli-Silva et al., 1988; Berggren et al., 1992).

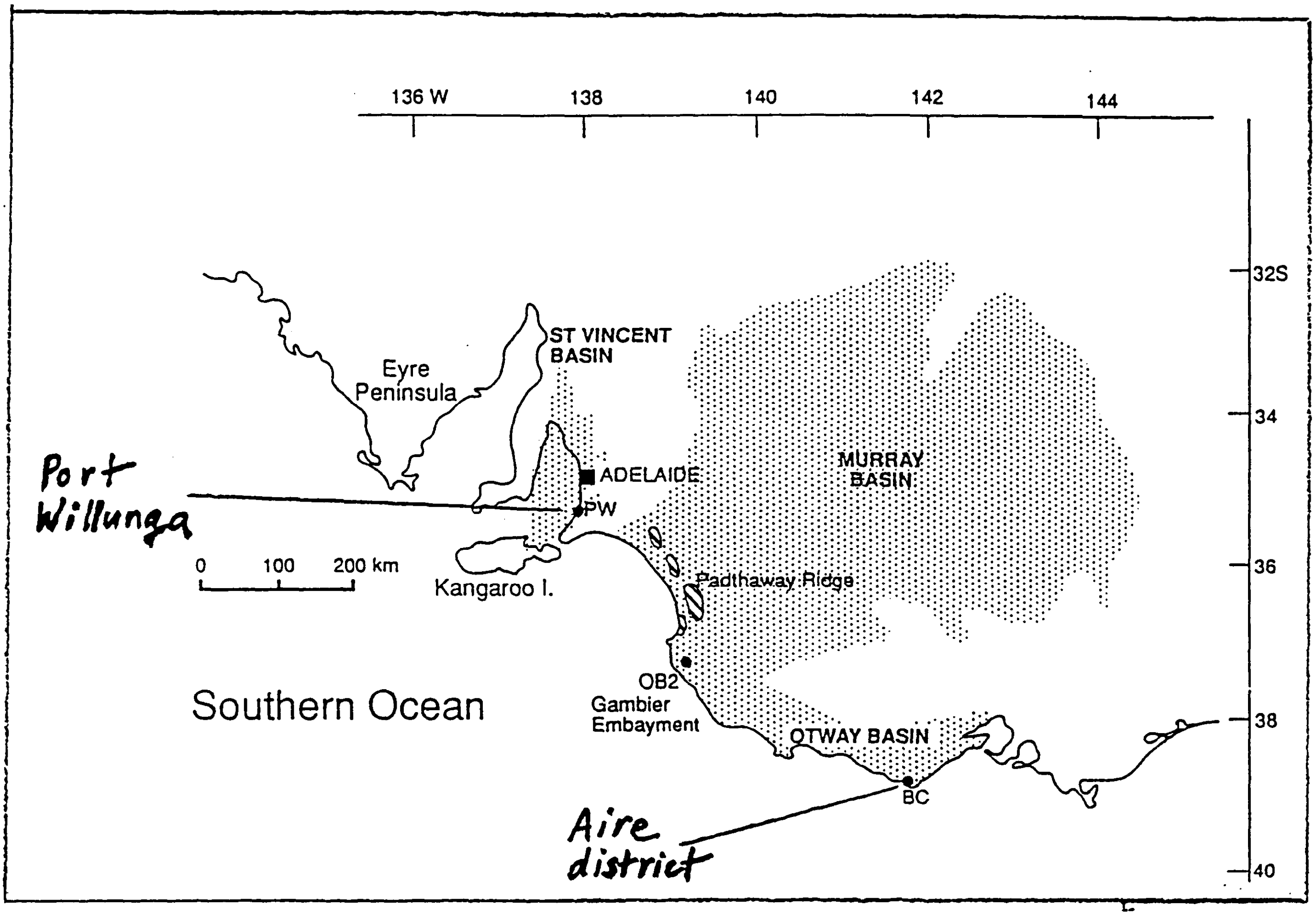


Fig. 1 LOCATION MAP
(= Moss & McGowran, 1993, Fig. 1)

Reliable recognition of Eocene and Oligocene in Australia has been based largely on correlation by means of microfossils - planktonic foraminifers and calcareous nannoplankton. However, precise correlation is difficult because the intercontinental P zones, characterised by tropical planktonic foraminiferal assemblages, are hard to recognise in southern Australia which lay outside low latitudes during the Palaeogene.

In the late 1950s the Eocene/Oligocene boundary in Australia was recognised at the last appearance (LAD) of *Globigerinatheka index* (Carter, 1958; Glaessner, 1959), in the 1960s also at LAD *Subbotina linaperta* (Wade, 1964; Taylor, 1966; Ludbrook & Lindsay, 1966; Lindsay, 1967). This has fluctuated: McGowran (1973) and Abele (1976) used LAD *G.index*, Lindsay (1985) and Lindsay & McGowran (1986) LAD *S.linaperta*, and Tickell et al. (1992) and Moss & McGowran (1993) again LAD *G.index* as the most appropriate criterion.

Calcareous nannofossils from the Aire district have been studied by Shafik (1981, 1983) and Waghorn (1989); Waghorn accepted LAD *Discoaster saipanensis* as marking the Eocene/Oligocene boundary.

During the last few years other approaches to recognising the boundary have been tried. Kamp et al. (1990) established a planktonic foraminiferal oxygen-isotope stratigraphy for the Aire district sections, estimated variations in sea-surface palaeotemperature, and interpreted a cooling as representing the Terminal Eocene Event (TEE). McGowran et al. (1992) recognised a Chinaman Gully regression in both St Vincent and Otway basins, and correlated it both with the TEE cooling and the Exxon cycle 4.3/4.4 boundary which was equated with the Eocene/ Oligocene boundary by Haq et al. (1987).

The completion of a planned manuscript by several authors (mentioned in nomen nudum 22, September 1993), integrating biostratigraphy and magnetic reversal stratigraphy of the Browns Creek section, has been delayed (S.Shafik, pers. comm., December 1993).

LOCATION AND ROCK UNIT NOMENCLATURE

Tertiary strata outcrop along the coast and inland in two small areas in the Aire district on the southwestern margin of the Otway Ranges (Figs 1, 2 and 3). A local scheme of rock unit nomenclature was established by O.P. Singleton, outlined by Thomas (1957) and discussed in greater detail by Carter (1958), Singleton (1967) and Abele et al. (1976). The Browns Creek Clay (also called the Browns Creek Formation), Castle Cove Limestone and Glen Aire Clay (= 'Lower Glen Aire Clays') were included by Tickell et al. (1992) in the Narrawaturk Marl which is widespread in the eastern Otway Basin. However, the local names are still useful in detailed discussion of the biostratigraphically important coastal sections.

The upper part of the underlying Johanna River Sand (also called Johanna River Formation) at Browns Creek and the whole of the unit at Castle Cove are referable to the Demons Bluff Formation. The Calder River Limestone and the Fishing Point Marl (including 'Upper Glen Aire Clays') are regarded as synonyms of the Clifton Formation and Gellibrand Marl respectively.

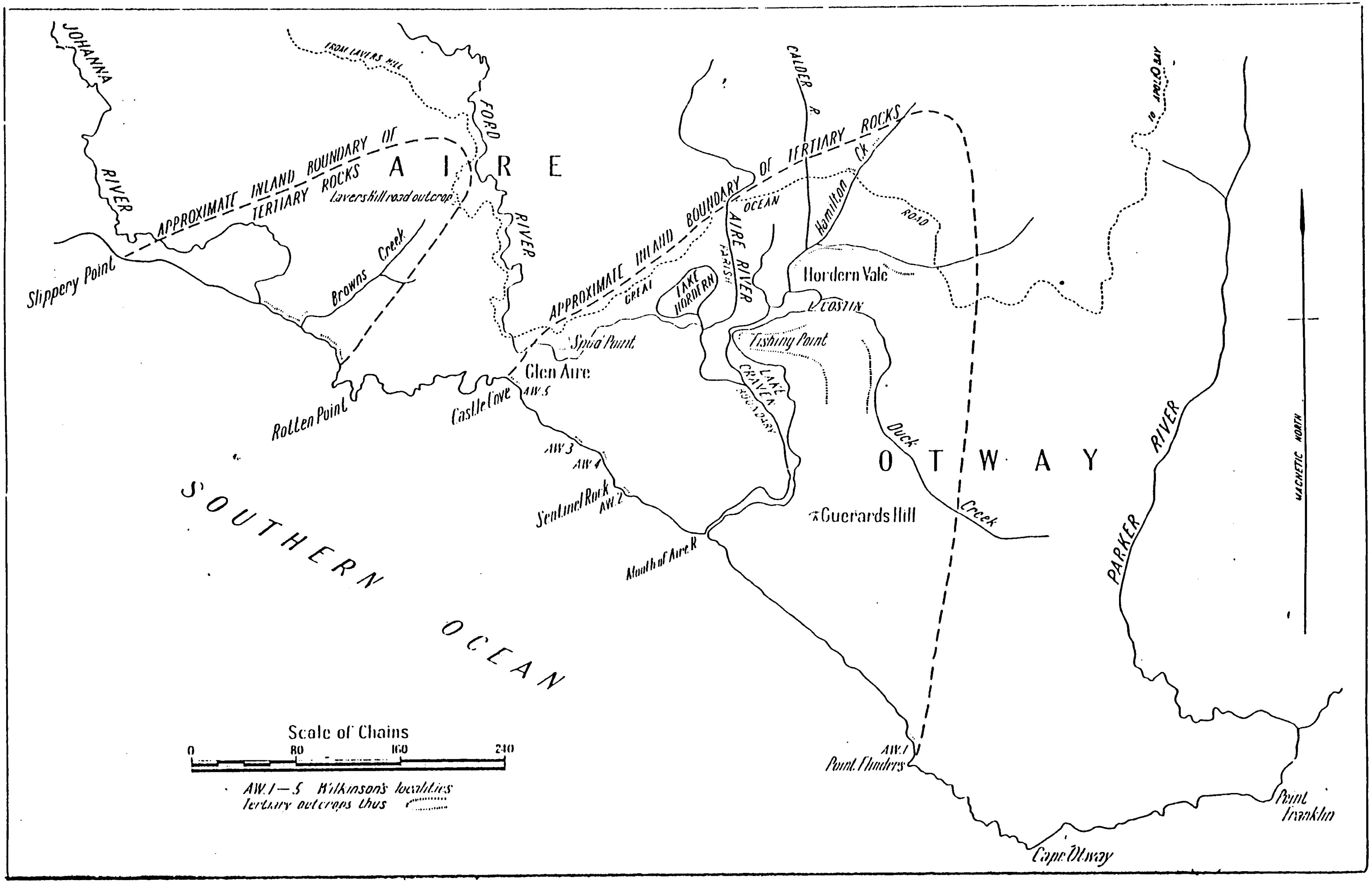


Fig. 2 AIRE DISTRICT (= Carter, 1958, Text-fig. 1)

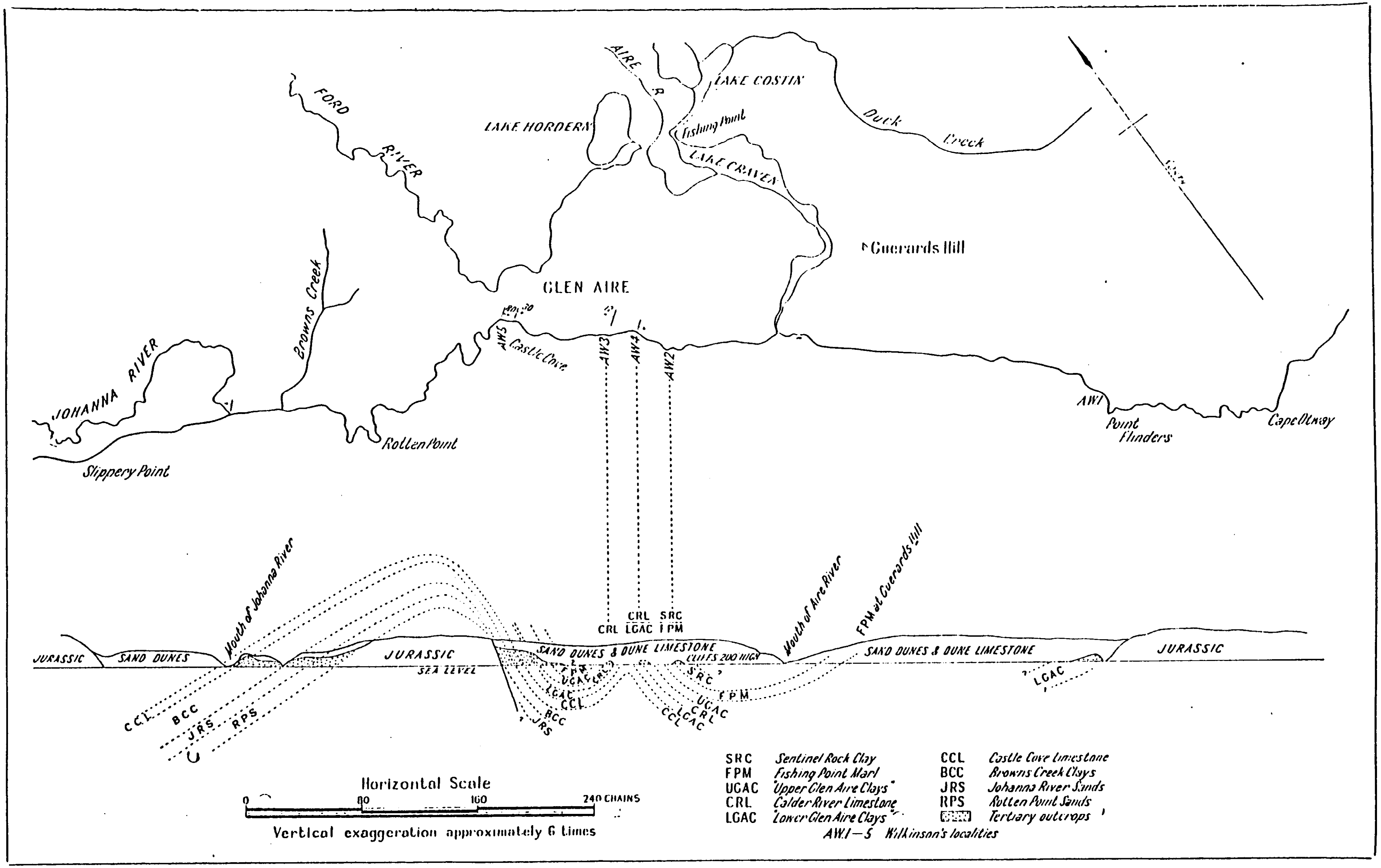


Fig.3 AIRE DISTRICT COASTAL SECTIONS (= Carter, 1958, Text-fig. 2)

BROWNS CREEK SECTIONS (Fig. 4)

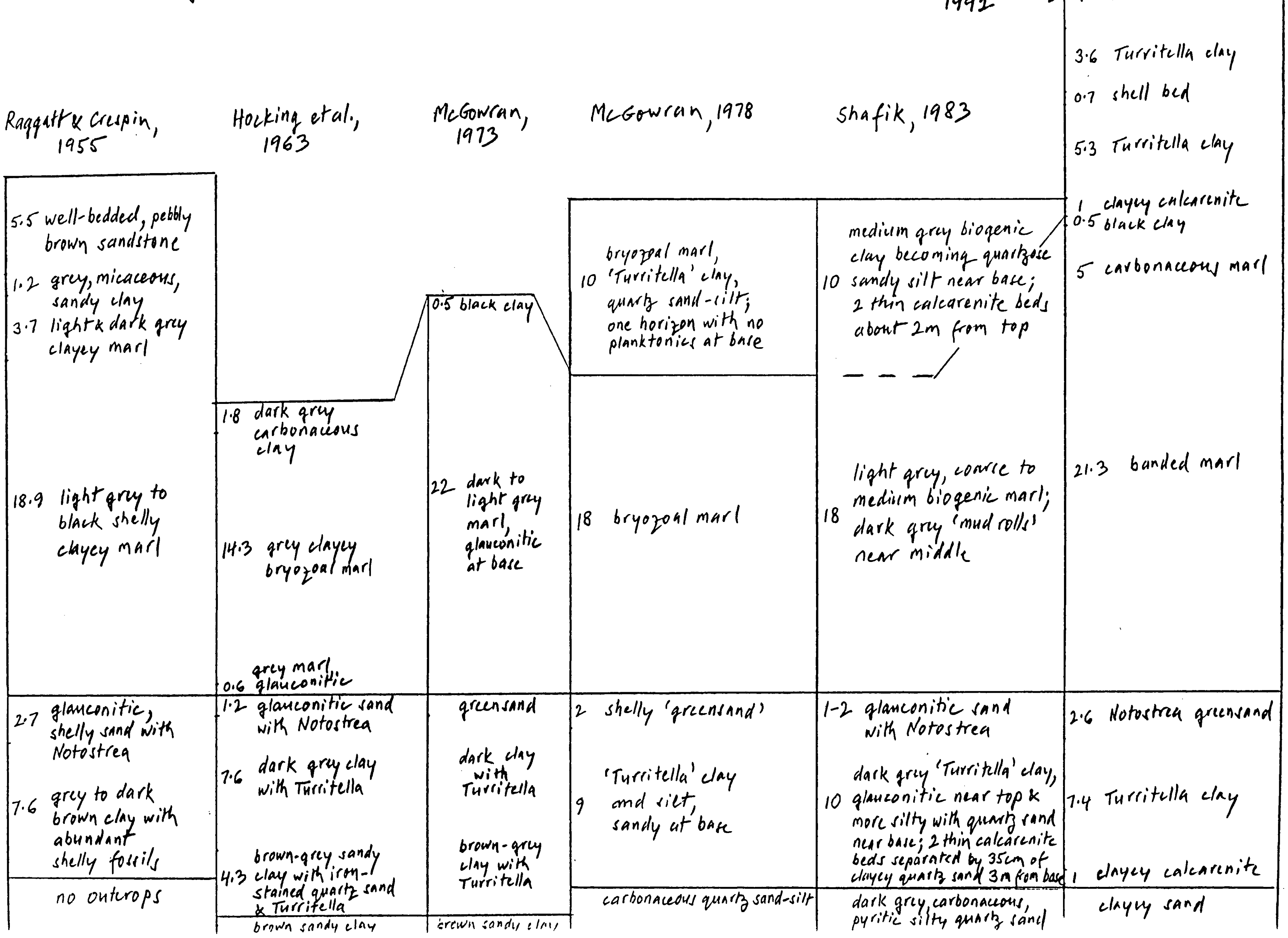
Parr (1947) recorded *Hantkenina* from glauconitic clay and the overlying highly glauconitic bed with abundant *Notostrea* outcropping near the mouth of Browns Creek. Raggatt & Crespin (1955) measured almost 40 m of strata exposed in gullies between mouth of Browns Creek and mouth of Johanna River, including the bed of glauconitic shelly sand with *Notostrea*.

Much of the subsequent work on foraminiferal and calcareous nannoplankton biostratigraphy has been related to the Browns Creek Clay section measured in the first gully west of Browns Creek by Hocking, McGowran and Taylor in October 1963 (Fig. 1 in Cookson & Eysenack, 1965) or modified and/or expanded versions of it (McGowran, 1973, 1978; Shafik, 1983; Tickell in Tickell et al., 1992). The glauconitic shelly sand ('greensand') is a prominent feature of all measured sections, although estimates of its thickness have varied from less than 1 to more than 2 m.

Apart from the greensand, the Browns Creek outcrops lack clear-cut marker beds or sharp, laterally persistent changes in lithology. The degree of exposure has also varied over the years. In places the sections slope steeply and accurate measuring of thickness is difficult. As a result, thickness estimates of strata above the greensand and, to a lesser extent, of those below, have varied, as have their lithological descriptions.

Thus - Hocking and others in 1963 recorded at the top of the section 1.8 m of dark grey carbonaceous clay 14.9 m above the glauconitic sand. McGowran (1973) showed, also at the top of the section, 0.5 m of black clay 23.3 m above the base of the greensand; a sample from the top of the clay contains rare steinkerns of planktonic foraminers with common aragonitic benthonic foraminifers and small gastropods, indicating regression. According to McGowran (1978), the horizon with no planktonics (except steinkerns) is 18 m above the top of the greensand and is overlain by 10 m of bryozoal marl, *'Turritella'* clay and quartz sand-silt. Shafik (1983) also showed 28 m of sediments above the

Fig. 4 BROWNS CREEK SECTIONS



glauconitic sand. Tickell in Tickell et al. (1992) placed a 0.5 m thick black clay layer (at the top of carbonaceous marl) 26.4 m above the greensand; above the black clay are a further 15 m of Browns Creek Clay, overlain by Pliocene sand (thicknesses were estimated from Tickell's drawn section, they are not actual measurements).

Tickell stated explicitly that his Browns Creek section is composite, comprising partly overlapping sections exposed in two large erosion gullies 50 and 100 m northwest of the mouth of Browns Creek. In the first gully Browns Creek Clay strata up to 26 m above the greensand are exposed; younger beds of the unit outcrop only in the second gully, a little farther northwest.

It appears that the uppermost 10 m in the sections of McGowran (1978) and Shafik (1983) were also described from the second gully. Later, however, McGowran (pers. comm., February 1994) considered that his 1978 section was based on misinterpretation.

The sections in both first and second gullies were examined and measured once again in March 1994 by S.Ryan, B.Simons and L.Knight, while I collected additional samples. Our observations, although differing somewhat in thickness and lithological details, strongly support Tickell's composite interpretation of the Browns Creek section. They also strongly suggest that the uppermost 10 m in the sections of McGowran (1978) and Shafik (1983) are exposed in the second gully.

The Tertiary beds between the mouths of Browns Creek and Johanna River dip gently to the northwest, as shown by Carter (1958, Text - fig. 2; see Fig. 3 here) and Tickell et al. (1992, Fig. 13). Thus strata in the upper part of the second gully overlie those in the first gully, and are in turn overlain by the Castle Cove Limestone outcropping at the mouth of Johanna River. As there are no distinct marker beds common to both gullies, precise correlation between them is difficult, in spite of their nearness to each other. However, the 'banded marl' in the lower part of the second gully section closely resembles strata in the upper part of the first gully. In addition, a fairly accurate correlation can be achieved by recognition of two foraminiferal datums in both gullies, as discussed a little later.

Simplified and slightly modified versions of the sections measured by S.Ryan, B.Simons and L.Knight are used here for plotting the levels of A series samples (A for Aire district) and biostratigraphic datums (Figs 5 and 6). More detailed sections are included as an appendix.

Accurate sample levels are important for detailed biostratigraphy. I collected samples A 33 to A 44 in 1977 in the first gully just northwest of the mouth of Browns Creek. The positions of samples A 33 to A 42 were measured with Jacob's staff and level relative to the top of the greensand. The levels of samples A 35 to A 42 can be regarded as fairly accurate. Sample A 34 came from the lowest richly fossiliferous bed 8.5 m below the top of the greensand, sample A 33 from the lowest exposed in situ bed 0.6 m below A 34. In 1977 I did not record the thin calcarenite layer near the base of the section, and the relationship of samples A 33 and A 34 to this layer is not clear. Foraminifers indicate that A 34 is from strata equivalent to the calcarenite bed or a little above it. Sample A 33 yielded no foraminifers and presumably comes from a level below the calcarenite bed.

I collected sample A 44 from black fossiliferous clay near the top of Browns Creek Clay and A 43 from about 3 m below the top. The distance of these samples above the greensand was not measured, and their plotted levels in Fig. 5 are less accurate than those of other samples. Apparently the highest Browns Creek Clay beds were less well exposed in 1977 than today; foraminifers show that sample A 44 comes from below the level of the recently collected A 55.

Samples A 45 to A 54 were collected in 1993 by B.Simons, J.Edwards and D.Perincek. All except A 45 were collected in the second gully and all were related directly to the section measured by Tickell; hence their levels can be plotted fairly accurately.

Fig. 5 BROWNS CREEK : SECTION IN 1st GULLY

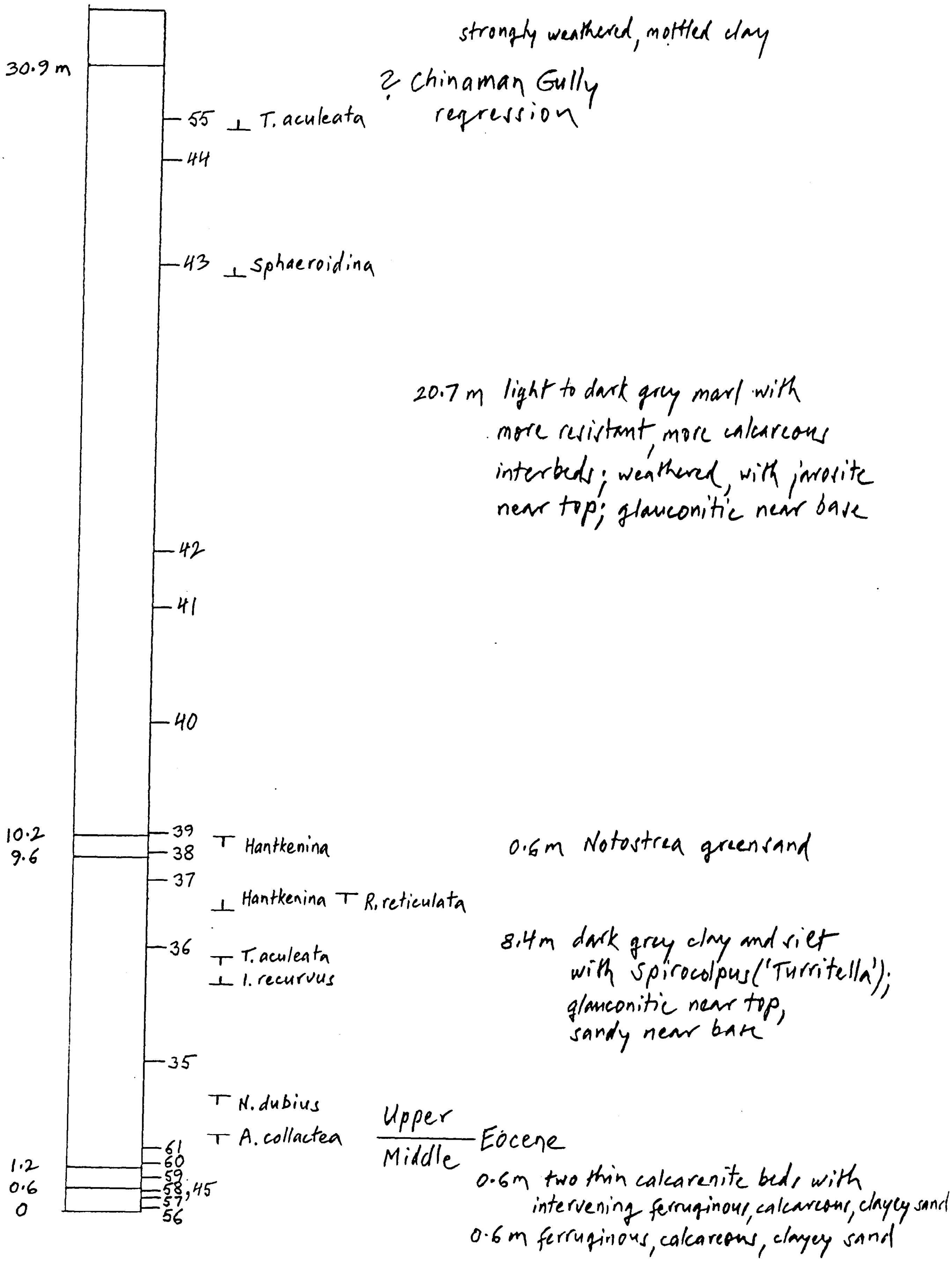
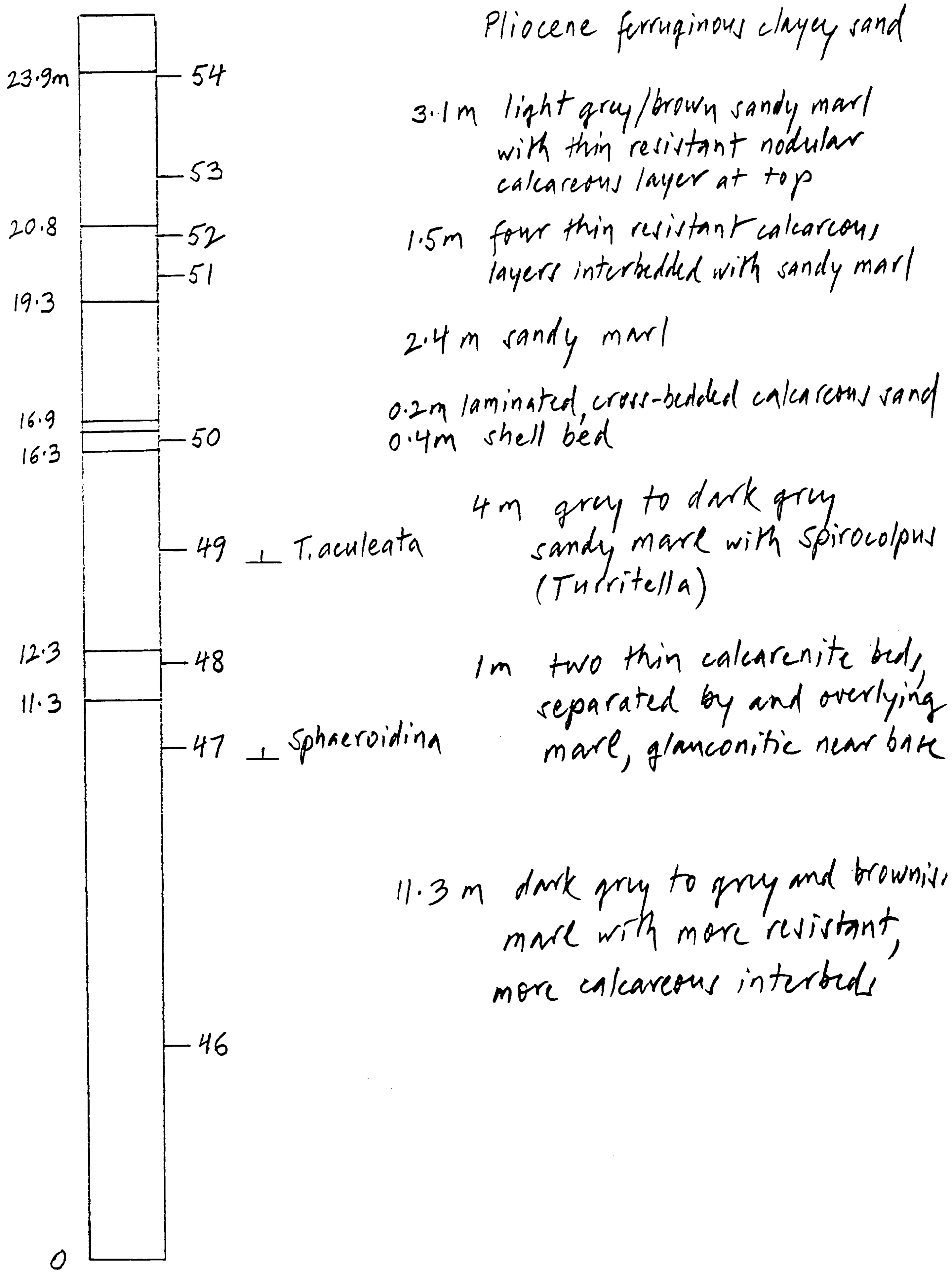


Fig. 6 BROWNS CREEK: SECTION IN 2nd GULLY



I collected samples A 55 to A 61 in the first gully during remeasuring of the section in March 1994. Samples A 56 to A 61 are from 50 cm below, 25 cm below, just below, within, just above and 50 cm above the 60 cm thick twin calcarenite layer near the base of the section. Sample A 55 comes from the highest obviously fossiliferous, not strongly weathered bed 19.3 m above the greensand (1.4 m below the top of dark weathered marl/clay).

Two foraminiferal datums, discussed in more detail later, help to correlate the sections in the two gullies. The reappearance of the planktonic *Tenuitella aculeata* (i.e. the base of the upper part of its disjunct range) is between samples A 44 and A 55 in the first gully and between samples A 48 and A 49 in the second gully. The benthonic *Sphaeroidina* is present in A 43 and higher samples from the first gully, and in A 47 and higher in the second gully. As discussed earlier, the levels of A 43 and A 44 are approximate, but tentatively the level of sample A 43 correlates with that of A 47, and A 55 with A 49. This indicates that the sections in the two gullies overlap somewhat more than shown by Tickell.

The outcrops of Castle Cove Limestone just southeast of the mouth of Johanna River were also sampled. I collected sample A 4 in 1968 from near the base of the exposure at beach level, and samples A 62 and A 63 in March 1994 from stratigraphically successively higher levels along the cliff face to the east.

CASTLE COVE SECTION

The most detailed and most commonly referred to section is that measured along the beach at Castle Cove by O.P. Singleton, A.N. Carter and W.Esplan in 1953 and 1954, and published in Carter (1958, Text - fig. 3). It was measured at times of excellent exposure; beach sand commonly covers much of the section. Numbers with prefix CC indicate levels of samples collected by Singleton and Carter; they are also useful as indicators of specific layers in discussion of the stratigraphy.

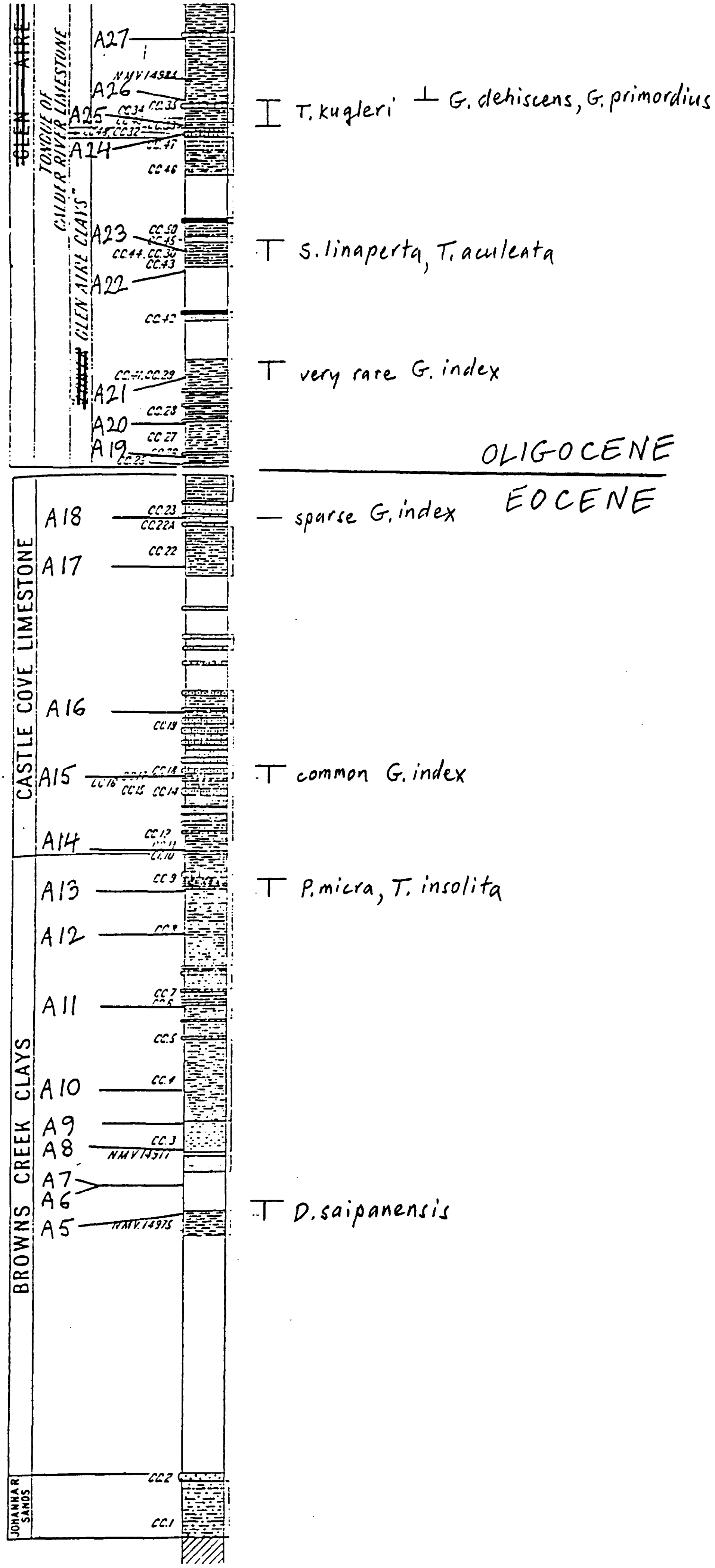
Exposure was good enough in August 1970 to enable me to collect samples A 5 to A 27 (Fig. 7) and relate them accurately to the section in Carter (1958). During later visits the outcrops have been poorer.

Horizontal distances measured perpendicular to the strike can be converted to true thicknesses after measuring or estimating the angle of dip. Carter (1958, Text - fig. 2; Fig. 3 here) showed 80° and 30° dips at Castle Cove.

The only bed dipping at 80° is the 2′ ferruginous sandstone at CC 2. The lowest bed above that where I could measure a dip of 45° in 1970 is the limestone layer at CC 7. The CC 9 layer dips at 40°, others up to CC 19 at 35°-45°. Limestone layers from CC 22 A upwards to the Calder River Limestone and higher dip at 30°.

My thickness estimates agree reasonably well with Carter's in the upper part of the section, above CC 22 A, on the basis of a 30° dip. They vary significantly in the lower part of the section where Carter appears to have assumed much steeper dips than 45°. However, for ease of reference and continuity, Carter's Castle Cove section is left unchanged. In this case exact thickness is less important than precise reference of samples to levels in the section.

Fig. 7 CASTLE COVE SECTION (after Carter, 1958, text-fig. 3)



FORAMINIFERA

Carter (1958) briefly discussed previous work on foraminifers from the Aire district, identified 65 and described 38 species, and showed their approximate ranges, including those of *Subbotina linaperta*, *Globigerinatheka index*, *Hantkenina primitiva* and *Pseudohastigerina micra* (currently accepted generic and specific names are used here). In addition to a few other species, Ludbrook & Lindsay (1969) recorded *Turborotalia centralis* and *T.increbescens* from the Browns Creek Clay, and *Tenuitella gemma*, *T.acculeata* and *Subbotina angiporoides* from higher in the section.

McGowran (1978) gave a useful summary of the planktonic foraminiferal succession in the Upper Eocene of the Aire district. McGowran & Beecroft (1986, p. 26) recorded the important *Acarinina collactea* from near the base of the Browns Creek section and McGowran (1989, p. 52) listed other species occurring with it.

McGowran & Beecroft (1986), McGowran (1987) and McGowran et al. (1992) investigated the incoming and outgoing of foraminiferal species, and variation in abundance of species and larger groupings, in the Browns Creek Formation at Browns Creek.

Figs 8, 9 and 10 show the distribution and largely qualitatively estimated abundance of planktonic foraminifers in the Browns Creek and Castle Cove sections. A = abundant, C = common, S = sparse, R = rare (less than 10 specimens), V = very rare (less than 5 specimens).

Fig. 8 DISTRIBUTION CHART OF PLANKTONIC FORAMINIFERS IN BROWNS CREEK 1ST GULLY SECTION

	Browns Creek Clay																			
	33	56	57	58	45	34	59	60	61	35	36	37	38	39	40	41	42	43	44	55
Acarinina collactea				C	C	C	C	C	C											
Pseudohastigerina micra					V			V		V	C	A	V		V	R	C			
Hantkenina primitiva												V								
Tenuitella aculeata				C	S	S	C	C	C	S										S
insolita				V	V		V		R			S	R	V	S	S	R	V	V	
gemma				V	V							R	V	S	S	C	C	R	S	R
munda																				
Chiloguembelina cubensis				S	S	R	C	C	C	V	V	C	S	R	S	C	C	S	R	A
Globigerina praebulloides group				S	S	S	S	R	R	C	C	C	C	C	A	C	C	C	C	A
'Globigerina' labiacrassata																				
Globigerinatheka index		V	V	C	C	C	A	A	C	C	A	A	C	A	A	C	C	A	C	
Subbotina linaperta/angiporoides		V		S	C	S	S	R	S	R	C	C	C	C	A	C	C	C	C	C
'Globigerina' brevis																			R	C
Turborotalia centralis														R						
increbescens				S	R	C	C	C	C		V								V	C
nana				V			V	S	C	C	A								V	
Globorotaloides suteri				V	R						R	S	V	V	R	V	S	S	S	

A abundant
C common
S sparse
R rare
V very rare

Fig. 9 DISTRIBUTION CHART OF PLANKTONIC FORAMINIFERS IN BROWNS CREEK 2ND GULLY SECTION AND AT MOUTH OF JOHANNA RIVER

	Browns Creek Clay										Castle Cove Ls		
	46	47	48	49	50	51	52	53	54		4	62	63
Acarinina collactea					V				V				
Pseudohastigerina micra	C	V				V							V
Hantkenina primitiva													
Tenuitella aculeata				S	V	V	V	R					
insolita	R	A				V		V	V				
gemma	C	A	R	S	S	C	V	C	C		S	C	A
munda													
Chiloguembelina cubensis	C	A	V	S	S	C	S	C	S		S	A	A
Globigerina praebulloides group	A	A	C	C	C	A	C	C	C		S	A	A
'Globigerina' labiacrassata													
Globigerinatheka index	A	A	V	V	C	C	C	C	C		C	S	S
Subbotina linaperta/angiporoides	A	A	A	C	A	C	C	C	C		C	C	C
'Globigerina' brevis				C	R	R	R	R	S		S	R	R
Turborotalia centralis													
increbercens			S	S				V	V		V		
nana			V		V			V					V
Globorotaloides suteri	C	S	V		R	S	S	S	C		R	R	S

Fig. 10 DISTRIBUTION CHART OF PLANKTONIC FORAMINIFERS IN CASTLE COVE SECTION

	Browns Creek Clay									Castle Cove Ls					Glen Aire clay				
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Acarinina collactea				V	R	V	V												
Pseudohastigerina micra	C					V	V		V										
Hantkenina primitiva																			
Tenuitella aculeata		R	V	V	R	V	V		V									C	C
insolita	C				V		V		V										
gemma		C	S	R	C	C	R	V	S	R	V			S					
munda															V	C	A	C	C
Chiloguembelina cubensis	C	C	S	V	C	S	C		C	S	R			S	V	V	S	R	R
Globigerina praebulloides group	A	A	C	A	A	C	A	S	A	C	S	S		S	C	A	A	A	A
'Globigerina' labiacrassata																		C	C
Globigerinatheka index	A		S	A	A	A	A	A	A	C	C	V		S	R	V	V		
Subbotina linaperta/angiporoides	C	A	A	A	A	A	A	A	A	C	C	C		C	C	A	A	C	C
'Globigerina' brevis		S	A	C	S	R	C	C		S	C	C						S	
Turborotalia centralis																			
increbescens	C	R	R	R	C	V	C		R	R				C	V				
nana				R	S	V	V	V	V		V						C		R
Globorotaloides suteri	C	S	S		C	C	C	C	C	C	C	R		S	R	C	R	R	

Taxonomic remarks

Tenuitella gemma differs from *T.munda* in having more chambers in the last whorl (usually 5 compared with 4). Commonly in assemblages of *T.gemma* there are some specimens morphologically referable to *T.munda* and vice versa.

The *Globigerina praebulloides* group also includes *G. ouachitaensis*, *G. officinalis* and *G.angustiumbilicata*.

I did not attempt to distinguish *Subbotina linaperta* and *S.angiporoides*. The assemblages include typically fairly coarsely cancellate specimens and forms with more finely textured walls. As the umbilicus becomes slightly wider and the aperture less distinctly lipped, less slit-like, specimens increasingly resemble *'Globigerina' brevis* (and presumably the *tripartita* group of McGowran, 1978), a few also *Turborotalia euapertura*.

T.increbescens includes specimens resembling *T.ampliapertura* and/or *T.pseudoampliapertura*. Although *T.ampliapertura* has been considered to have evolved from *T.increbescens* and *T.pseudoampliapertura* from *T.centralis* (e.g. Blow, 1969), other authors have regarded the distinction between the two as dubious or difficult (e.g. Stainforth et al., 1975; Bolli & Saunders, 1985). It has been generally accepted that *T.ampliapertura* originated in Late Eocene; however, Lindsay (1985), Lindsay & McGowran (1986) and McGowran et al. (1992) placed its appearance near LAD *Globigerinatheka index*, a little above the Eocene/Oligocene boundary (McGowran et al., 1992).

Turborotalia nana includes specimens with fairly high-arched apertures, resembling *T. pseudocontinuosa*.

Globorotaloides suteri includes specimens resembling *G.testarugosa*.

DATUM LEVELS

Various datum levels, mostly first or last appearances of foraminifers and nannofossils, are shown in Figs 5, 6 and 7.

Castle Cove section

Globorotalia kugleri s.l. is present in samples A 25 and A 26, *Globoquadrina dehiscens* and *Globigerinoides primordius* first appear in sample A 26. These strata are thus close to the Oligocene/Miocene boundary and beyond the scope of this investigation.

LAD *Subbotina linaperta*

Carter (1958) showed *S.linaperta* ranging up to the top of the Glen Aire Clay; his concept of the species included 'compact tests with swollen chambers' later distinguished as *S.angiporoides*. McGowran (1989) stated that *S.linaperta* extends up to the unconformity at the top of Glen Aire Clay.

The highest sample with *S.linaperta* is A 23. Only *Cyclammina* has been recorded from Glen Aire Clay strata above this level.

LAD *Tenuitella aculeata*

Ludbrook & Lindsay (1969) recorded *T.aculeata* from the Glen Aire Clay and Castle Cove Limestone. McGowran (1973) stated that *T.aculeata* is well developed in Glen Aire Clay and Browns Creek Clay, but regarded its occurrence above the beds with *Hantkenina* as anomalous. Later McGowran (1978, 1989) accepted the disjunct range of *T.aculeata* in the Aire district.

T.aculeata is common in Glen Aire Clay samples A 22 and A 23. I have not seen it in samples from Castle Cove Limestone, but it occurs rarely in sample A 13 and below in the Browns Creek Clay.

LAD *Globigerinatheka index*

Carter (1958, p. 26) stated that *G.index* ranges through at least the lower third of the Castle Cove Limestone; it 'is not known at present above sample CC 19.... but further work may extend its range a little higher ....'.

McGowran (1978) equated the top of *G.index* with the top of Castle Cove Limestone. Lindsay (1985, p.211) stated that 'the occasional immature single-apertured specimen (apparently not remanié) has now been found in basal Glen Aire Clay'.

I have found very rare, small specimens without supplementary apertures in the lowest three samples from the Glen Aire Clay - A 19 (6 specimens), A 20 (3) and A 21 (1). *G.index* is sparse in uppermost Castle Cove Limestone (sample A 18) but is common to abundant in its lower beds (A 15, A 14) and in the Browns Creek Clay.

LAD *Tenuitella insolita*

McGowran (1978) equated the top of *T.insolita* with the top of Castle Cove Limestone. I have not found this species above the Browns Creek Clay (sample A 13).

LAD *Pseudohastigerina micra*

Carter (1958) showed *P.micra* ranging up to the top of the Browns Creek Clay. I have not found it above uppermost Browns Creek Clay sample A 13 at Castle Cove, but I have recovered one specimen from sample A 63 from the Castle Cove Limestone at the mouth of Johanna River.

LAD *Discoaster saipanensis*

Waghorn (1989) recorded very rare *D.saipanensis* in sample A 5 (Waghorn used the prefix CC) from lower Browns Creek Clay as marking the top of its range. However, he observed two specimens, possibly reworked, in samples A 13 and A 14.

Browns Creek sections

LAD *Discoaster saipanensis*

Shafik (1983) noted the presence of *D.saipanensis* in uppermost Browns Creek Clay, within the upper part of the disjunct range of *Tenuitella aculeata* (interval D, Shafik's Fig. 5). However, he thought that *D.saipanensis* may have preferred deeper water and that its sporadic record in the Browns Creek Clay may not indicate true extinction.

Only samples A 34 to A 44 from the first gully, not A 46 to A 54, were available to Waghorn (1989). He placed the LAD of very rare *D.saipanensis* between samples A 42 and A 43, below the reappearance of *T.aculeata*.

Reappearance of *Tenuitella aculeata*

McGowran (1978) showed the base of the upper part of the disjunct range of *T.aculeata* at 18 m above the greensand. I place it between samples A 44 and A 55 in the first gully, and between A 48 and A 49 in the second gully.

This is the upper of two foraminiferal datums useful for correlation between the first and second gullies. Support for the validity of this datum is provided by *Globigerinatheka index* being absent from sample A 55 (but common to abundant in lower samples) and very rare in A 49 (also very rare in A 48 but common to abundant in lower and higher samples).

The absence of *G.index* from sample A 55, i.e. from uppermost strata in the first gully section, agrees with McGowran's (1973) and McGowran et al. (1992) recorded disappearance of the species below the top of the Browns Creek section (excluding beds in the upper part of the second gully). *Chiloguembelina cubensis* is abundant in A 55; this appears to agree with spike f in McGowran et al. (1992, Fig. 9.7).

Appearance of *Sphaeroidina*

As part of studies of turnover and abundance patterns of foraminiferal species and larger groupings in the St Vincent and Otway basins, McGowran et al. (1992 and earlier papers) showed the benthonic *Sphaeroidina* as appearing about 11 m above the greensand. I have found common *Sphaeroidina* in A 43 and higher samples from the first gully section, and in A 47 and higher samples from the second gully. This is the lower of two foraminiferal datums useful for correlating between the two gullies.

Range of *Hantkenina*

McGowran (1973, 1978) showed *Hantkenina* as ranging from the top of the shelly greensand down into the uppermost part of the underlying clay. Shafik (1981, 1983) gave its range as 2.9 and 2 m respectively.

I have found *Hantkenina* only in sample A 37.

LAD *Reticulofenestra reticulata*

Shafik (1981, 1983) showed *R.reticulata* (as *Cyclicargolithus reticulatus*) as ranging up to 1.7 and 1 m respectively below the top of the greensand. Waghorn (1989) recorded *R.reticulata* from sample A 36 and *R.* cf. *reticulata* from A 37.

FAD *Tenuitella gemma*

McGowran (1978) and Shafik (1983) equated FAD *T.gemma* with FAD *Hantkenina* at Browns Creek. I have found very rare *T.gemma* in samples A 45 and A 58 from near the base of the section, below the top of 'lower' *T.aculeata* and slightly below the top of common *Acarinina collactea*.

Lindsay (1985) placed FAD *T.gemma* below the top of 'lower' aculeata in the St Vincent Basin. Abele (1992) recorded the overlap of *T.gemma* and common *A.collactea* in gravity core and dredge samples from offshore Otway Basin.

Lower 'LAD' *Tenuitella aculeata*

McGowran (1973, 1978) showed *T.aculeata* as temporarily disappearing below FAD *Hantkenina*, according to Shafik (1983) 0.5 m below. I have not seen *T.aculeata* higher than sample A 35 in this part of the section.

FAD *Isthmolithus recurvus*

Shafik (1981, 1983) placed FAD *I.recurvus* 2.6 and 2 m below FAD *Hantkenina* respectively. According to Shafik (1983), this level is 1.5 m below top of 'lower' *T.aculeata*.

Waghorn's (1989) lowest record of *I.recurvus* was from sample A 37; he recorded only *I.* cf. *recurvus* from A 36. These levels are above top of 'lower' *T.aculeata*.

LAD *Neococcolithes dubius*

Shafik (1981, 1983) showed LAD *N.dubius* 3.1 and 3 m below FAD *Isthmolithus recurvus* respectively. Waghorn (1989) recorded *N.dubius* from sample A 35.

LAD *Acarinina collactea*

A.collactea was recorded from near the base of the section by McGowran & Beecroft (1986) and McGowran (1989).

The species is common in samples A 34, A 45, and A 58 to A 61. Thus LAD of consistent and common *A.collactea* is above sample A 61 from 0.5 m above the basal twin calcarenite layer (and below sample A 35).

However, I have found very rare to rare specimens of *A.collactea* in a few samples from the uppermost Browns Creek section (A 50 and A 54) and from the lower part of the Castle Cove section (A 8, A 9 and A 10); sample A 8 also yielded one specimen of *A.primitiva*. I regard the *A.primitiva* as reworked; the *A.collactea* specimens may also be reworked. In the St Vincent Basin, however, Lindsay (1969, 1985) has recorded convincing *A.collactea* from above LAD *Hantkenina* and in his 1985 paper showed the species as extending less convincingly above LAD *Subbotina linaperta*.

LAD *Subbotina* cf. *frontosa*

McGowran (1978) recorded *S.* cf. *frontosa* from near the base of Browns Creek Clay. At that time *Acarinina collactea* had not been found in this section, but from observations in the western Otway Basin the LADs of both species were regarded as coeval.

Since the records of *A.collactea* from Browns Creek, the significance of *S.* cf. *frontosa* has diminished.

LATE EOCENE CORRELATION

The Middle/Late Eocene boundary was placed at the P 14/P 15 zone boundary by Harland et al. (1990) and within Zone P 15 by Berggren et al. (1985, 1992).

LAD *Acarinina collactea* (excluding rare, sporadic higher occurrences) in southern Australia was placed in the lower part of Zone 15 by McGowran (1978, 1989) and in uppermost Middle Eocene (McGowran, 1989). The finding of *A.collactea* near the base of the Browns Creek section enabled McGowran & Beecroft (1986) and McGowran (1989) to recognise that the Tortachilla transgression, the second of four during the later Eocene in southern Australia, reached as far east as the Browns Creek area. McGowran et al. (1992) regarded the Tortachilla transgression, and hence LAD *A.collactea*, as very early Late Eocene. McGowran (1993, Figs 9 and 34) placed the beginning of the Tortachilla transgression in late Zone P 14 time, and LAD *A.collactea* in lower Zone P 15 at the same level as the Middle/Late Eocene boundary.

For routine work, I regard LAD *A.collactea* as the best approximation to the Middle/Late Eocene boundary.

McGowran et al. (1992) recognised a 'Tortachilla horizon' at the very base of the Browns Creek Formation, succeeded by the Tortachilla/Tuketja hiatus. They equated the unconformity with the sequence boundary between Exxon third order cycles 4.1 and 4.2. This boundary was placed within Upper Eocene by Haq et al. (1987).

Shafik (1983) noted that the lowest sample with calcareous nannofossils at Browns Creek contains *Chiasmolithus oamaruensis* but not *C.grandis*. LAD *C.grandis* and FAD *C.oamaruensis* mark the base of nannofossil Zone NP 18, commonly equated with the Middle/Late Eocene boundary, and Shafik regarded basal Browns Creek Clay as early Late Eocene in age, low in Zone P 15. At that time *A.collactea* had not been recorded from Browns Creek; in any case, Shafik considered that LAD *A.collactea* was inconsistent with other evidence. For example, Shafik stated that in the Gambier Embayment, unlike at Browns Creek, *A.collactea* ranges above FAD *Isthmolithus recurvus*. This, however, is not the case in

Observation Bore No. 2; according to McGowran (1973) the highest occurrence of *A.collactea* is at 135.1 m, but definite *I.recurvus* first appears at 134.1 m (Shafik, 1983, Table 5).

FAD *I.recurvus* was placed high in Zone 15 by Shafik (1981, 1983) and McGowran (1987). McGowran thought that this species may have appeared earlier in high latitudes and showed this level as below the base of Zone NP 19/20 which is defined as marked by first occurrence of *I.recurvus*, presumably in low latitudes. Waghorn (1989), however, accepted FAD *I.recurvus* at Browns Creek as marking the base of Zone NP 19/20. Berggren et al. (1985, 1992) showed this boundary as within Zone P 16, Harland et al. (1990) as low in Zone P 15.

The interval with *Hantkenina* was correlated with uppermost Zone P 15 by McGowran (1978, 1989). Shafik (1981, 1983) noted that LAD *Reticulofenestra reticulata* (= *Cyclicargolithus reticulatus*) is within this interval. He interpreted this as a true extinction at a level high in Zone P 16 and placed the *Hantkenina* interval at that level. Waghorn (1989), however, outlined evidence that the last occurrence of *R.reticulata* is strongly diachronous in the southwestern Pacific area. Aubry (1992) concluded that LAD *R.reticulata* corresponds to its extinction only in low, not in temperate and high, latitudes.

EOCENE/OLIGOCENE BOUNDARY

Events pertinent to the recognition of the Eocene/Oligocene boundary in southeastern Australia were discussed by Lindsay (1985), Lindsay & McGowran (1986) and McGowran et al. (1992; summary list in Table 9.2), from a different perspective also by Waghorn (1989) and Kamp et al. (1990).

Foraminifera

For routine age determination, a planktonic foraminiferal datum can serve as a good approximation to the Eocene/Oligocene boundary. Lindsay (1985) and Lindsay & McGowran (1986) considered the last appearance of *Subbotina linaperta*, carefully distinguished morphotypically from *S.angiporoides*, as a better indicator of the boundary than the somewhat earlier last appearance of rare and sporadic, single-apertured *Globigerinatheka index*.

Irrespective of the question as to which datum approximates the boundary more closely, a strong argument against the choice of LAD *S.linaperta* is the difficulty of distinguishing *S.linaperta* from *S.angiporoides*, in spite of Lindsay's (1985) detailed study. The two intergrade and a clear-cut separation can only be achieved on some arbitrarily defined grounds; however, Lindsay lumped morphologically transitional specimens as 'ex group *linaperta-angiporoides*'. *S.linaperta* has somewhat compressed chambers, with the length/width ratio less than 0.70; in transitional specimens this ratio is 0.70 - 0.75, in *S.angiporoides* more than 0.75. In addition, the last chamber in *S.linaperta* has a degree of 'undercut' around its base and is commonly wider than or as wide as the preceding part of the test, as discussed but not measured or quantified by Lindsay.

FAD *Cassigerinella chipolensis*, LAD *Tenuitella aculeata*, FAD *Guembelitria triseriata*, FAD *Turborotalia ampliapertura* and LAD *Tenuitella insolita* are not suitable datums for routine work because these species occur sporadically or rarely near the Eocene/Oligocene boundary.

I regard LAD *Globigerinatheka index* as the best approximation to the boundary for routine age determination. Although *G.index* is also rare and sporadic near the top of its range, it is probably less so than the above-mentioned species. *C.chipolensis* and *G.triseriata* have not been recorded from the Castle Cove section, and the two highest samples with common *T.aculeata* (A 22 and A 23) are separated from the next below occurrence (A 13) by the lower half of Glen Aire Clay and the whole Castle Cove Limestone. *G.index* occurs more consistently; although it is rare to very rare in lowermost Glen Aire Clay (A 19, 20 and 21), it is sparse in uppermost Castle Cove Limestone (A 18), and common to abundant in A 15 and lower samples. If the very rare and rare occurrences are ignored, LAD *G.index* can be placed at or near the top of Castle Cove Limestone.

Calcareous nannofossils

LAD *Discoaster saipanensis*, marking the boundary between zones NP 19/20 and NP 21, has been generally regarded as closely approximating or slightly below the Eocene/Oligocene boundary. Waghorn (1989) recognised this boundary between samples A 42 and A 43 in the Browns Creek section, and between samples A 5 and A 6 at Castle Cove.

As samples from the uppermost Browns Creek section (in second gully) were unavailable to Waghorn, his placement of the boundary at Browns Creek is clearly too low. The significance of very rare *D.saipanensis* recorded from sample A 5 from near the base of the Castle Cove section is questionable. Shafik (1983) did not have much faith in the sporadic record of this species in the Browns Creek section. Aubry (1992) stated that the last occurrence of *D.saipanensis* is one of the best known examples of diachronous ranges, time-transgressive from mid- to low latitudes.

Higher in the Castle Cove section, Waghorn (1989) showed *Ericsonia formosa* (= *Coccolithus formosus*) ranging up to sample A 16 and placed the Early Oligocene zone NP 21/NP 22 boundary between samples A 16 and

A 17 in the Castle Cove Limestone. The occurrence of *Sphenolithus distentus* near the middle of Glen Aire Clay (sample A 23) was taken to indicate an age no older than the mid-Oligocene Zone NP 23.

Aubry (1992), however, concluded that the last occurrence of *E.formosa* is diachronous, corresponding to extinction only in low latitudes. Aubry also showed *S.distentus* ranging down as low as Zone NP 21.

In comparing nannofossil and foraminiferal Eocene/Oligocene boundary markers in southern Australia and New Zealand, Waghorn (1989) noted marked differences. Because he regarded the nannofossil events as isochronous, he concluded that the foraminiferal events were diachronous (McGowran et al., 1992). He suggested that southern Australian nannofossil assemblages may have been more susceptible to early Oligocene cooling whereas planktonic foraminiferal assemblages survived for some time within a 'trapped' southern ocean watermass.

In the light of the foraminiferal evidence and Aubry's (1992) comments, Waghorn's assumption that the last occurrences of important nannofossils in the Castle Cove section and in low latitudes are isochronous, is difficult to accept, as is his palaeogeographical interpretation.

Coccolith ratio and oxygen isotope stratigraphy

Waghorn (1989) noted a pronounced decrease in the *Discoaster/Chiasmolithus* ratio, suggesting rapid cooling, between samples A 5 and A 6 near the base of the Castle Cove section. As this is at the level where Waghorn placed LAD *D.saipanensis*, he speculated that it may correlate with a widely recognised, marked enrichment of oxygen isotope values attributed to a decrease in marine palaeotemperatures at the Eocene/Oligocene boundary. Later Kamp et al. (1990) showed enrichment of 0.46 ‰ in planktonic $\delta^{18}O$ between samples A 5 and A 6. They recognised that this is rather small, but thought that the early part of the oxygen-isotope shift may not have been sampled.

The isotope evidence is hardly convincing. The small enrichment from sample A 5 to A 6 is overshadowed by the large depletion between samples A 9 and A 10. As this is not associated with any increase in the number of *Discoaster*, Kamp et al. dismissed it as perhaps reflecting some diagenetic overprint.

Kamp et al. (1990) also recorded enrichment of 1.04 ‰ in planktonic $\delta^{18}O$ between samples A 43 and A 44 in the Browns Creek section. As this is only slightly above their placement of LAD *D.saipanensis*, between samples A 42 and A 43, Kamp et al. speculated that the enrichment may signify terminal Eocene cooling. As discussed earlier, however, *D.saipanensis* ranges higher.

Event and sequence stratigraphy

McGowran (1978) summarised the Late Eocene planktonic foraminiferal succession in the Aire district, and correlated a regressive interval 10 m below the top of the Browns Creek section with the Chinamans Gully Bed in the St Vincent Basin as responses to some eustatic event. McGowran & Beecroft (1986) and McGowran (1987) found considerable similarities in incoming and outgoing of foraminiferal species, and in their abundance patterns, between the restricted neritic facies of the St Vincent Basin (Tortachilla-Blanche Point Formation) and the more open marine facies in the Otway Basin (Browns Creek Formation below the regressive interval). They regarded the Terminal Eocene Event (TEE) as a series of steps beginning well before the end of the Eocene, and McGowran (1987) placed the Chinaman Gully regression close to the Zone P 16/P 17 boundary, at the Exxon third order cycle 4.2/4.3 boundary (Haq et al., 1987).

McGowran et al. (1992) summarised and extended the earlier work, and their Fig. 9.7 shows event correlation between Blanche Point and Browns Creek, and sequence stratigraphy. They now correlated the Chinaman Gully regression with the major shift in oceanic $\delta^{18}O$ profiles, inferred to represent rapid cooling accompanied by a sea-level fall, and recognised this as a short, sharp TEE, rather than merely a conclusion to protracted late Eocene change. They also correlated the Chinaman Gully regression with the type 1 sequence boundary between Exxon cycles 4.3 and 4.4, placed at the Eocene/Oligocene and Chron C 13N/C 13R boundaries by Haq et al. (1987). As the latter is slightly younger than the proposed Eocene/Oligocene stratotype at Massignano, McGowran et al. thought that the Chinaman Gully regression and the TEE may be earliest Oligocene.

The distribution of planktonic microfossils is commonly controlled by incompletely understood factors and, as shown previously, there is often scope for different opinions and inconclusive arguments as to whether microfossil appearances and disappearances in different areas are coeval or not. Hence I fully sympathise with attempts to correlate the reflections in the rock record of regionally and globally recognisable geohistorical events. McGowran et al. (1992) stated that correlation of the Chinaman Gully regression with the major shift in $\delta^{18}O$ profiles and with the boundary between Exxon cycles 4.3 and 4.4 'makes all the difference in whether there is a satisfying fit between the local and the global story or a niggling misfit'.

Of course, this correlation accepts the basic premise behind the Exxon curves and cycles - that they are indeed eustatic and globally correlatable. There is still widespread reluctance to accept this as proven (Miall, 1992, gave a recent critique). Also, the correlation with the shift in $\delta^{18}O$ profiles is not supported by any isotopic evidence.

The concepts and terminology of sequence stratigraphy have only recently been applied to the Browns Creek section. Tickell's interpretation (Fig. 14 in Tickell et al., 1992) differs from that of McGowran et al. (1992). Earlier Shafik (1981, 1983) had discussed deposition in the Browns Creek area in terms of slow sedimentation resulting in a condensed section below the top of the greensand, and very rapid sedimentation leading to very shallow water during deposition of the succeeding expanded section.

Chinaman Gully regression and LAD *G.index*

Whether or not the Chinaman Gully regression is earliest Oligocene or approximates the Eocene/Oligocene boundary, there is another problem - that of recognition. In routine subsurface work, a suitable planktonic foraminiferal datum is more easily recognisable than a short-lived regression.

McGowran et al. (1992, Table 9.2) showed the Chinaman Gully regression as above the last appearance of abundant *Globigerinatheka index* but below that of rare *G.index*. This agrees with the situation in the St Vincent Basin where the extension of the range of *G.index* above the Chinaman Gully Formation (Lindsay, 1985; Lindsay & McGowran, 1986) is based on very few observed specimens (McGowran, pers. comm., February 1994). Moss & McGowran (1993, Fig. 3) equated the Chinaman Gully regression both with LAD *G.index* and the Eocene/Oligocene boundary. This supports the use of LAD *G.index* (rare, sporadic specimens presumably excepted) as the best approximation to the boundary for routine age determination.

Browns Creek

McGowran (1978) and in later papers, some with co-authors, has recognised the Chinaman Gully regression at Browns Creek 29 or 30 m above the base of the section, 18 m above the greensand. McGowran (1978) noted spectacular variation in abundance of *G.index* in a further 10 m of strata above the regressive interval. Later, however, McGowran (1987) referred to a sandy clay at the top of the exposed section at Browns Creek as an expression of the Chinaman Gully regression and, as already mentioned, in February 1994 stated that the section discussed in his 1978 paper was based on misinterpretation.

Clearly, the regressive horizon has been recognised at the top of the section in the first gully northwest of the mouth of Browns Creek, and it is the interval exposed in the first gully that has been correlated with the Tortachilla Limestone and Blanche Point Formation in the

St Vincent Basin (as summarised in Fig. 9.7 of McGowran et al., 1992). Just as clearly, the uppermost Browns Creek Clay beds in the first gully section are well below LAD *G.index*, which is common in samples A 50 to A 54 from the upper part of the second gully, and common to sparse in samples A 4, A 62 and A 63 from the overlying Castle Cove Limestone at the mouth of the Johanna River.

Thus - either an horizon at or near the top of the first gully section has been wrongly equated with the Chinaman Gully regression, or this regression took place well before the extinction of *G.index* near the end of the Eocene.

Castle Cove

After referring to the horizon of no planktonics 10 m below the top of the Browns Creek section, McGowran (1978) remarked that there is a similar horizon near the base of the Castle Cove section and speculated that the two may be the same. Shafik (1983) noted that nannofossil abundance and diversity decline drastically in the lower part of the Castle Cove section. McGowran (1989, p. 56) stated that the marine section at Castle Cove is above the regressive interval.

Nowadays, however, McGowran (pers. comm., February 1994) would look for signs of the Chinaman Gully regression in the Glen Aire Clay, above LAD of common *G.index*.

CONCLUSIONS

LAD *Acarinina collactea* (rare, sporadic specimens excepted) near the base of the Browns Creek section is the best approximation to the Middle/Late Eocene boundary.

LAD *Globigerinatheka index* (rare, sporadic specimens again excepted) at or near the top of the Castle Cove Limestone in the Castle Cove section is the best approximation to the Eocene/Oligocene boundary.

Outcrops of Browns Creek Clay and Castle Cove Limestone between the mouths of Browns Creek and Johanna River are Eocene, below LAD *G.index*.

The Browns Creek composite section comprises partly overlapping sections in two gullies just northwest of the mouth of Browns Creek; uppermost beds in the second gully are younger than those in the first gully.

An horizon near the top of the first gully at Browns Creek has been correlated with the Chinaman Gully regression in the St Vincent Basin in South Australia. Either the correlation is incorrect or the regression took place well before the extinction of *G.index* near the end of the Eocene.

CA:cg.1

6 May 1994

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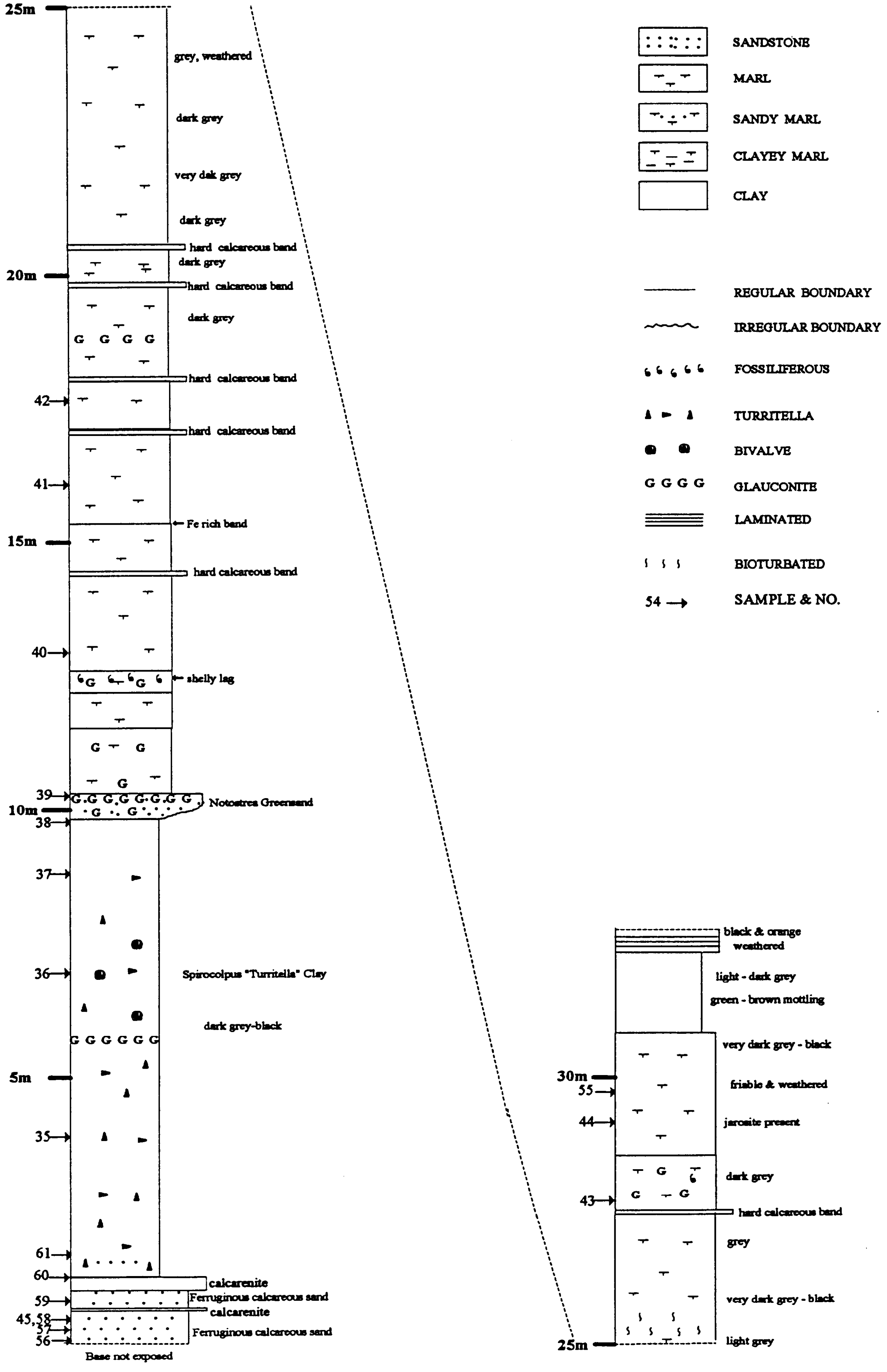
APPENDIX

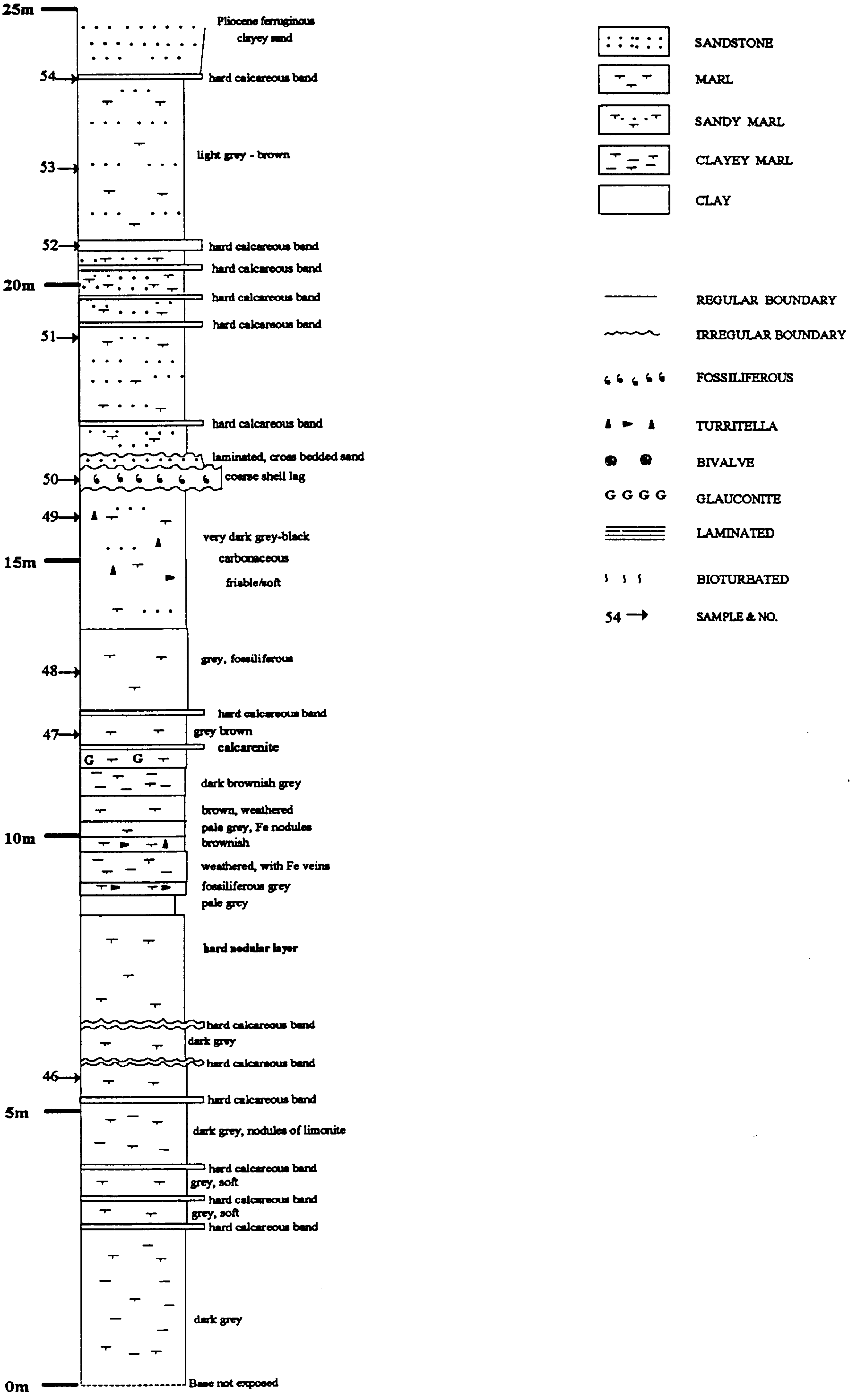
DETAILED SECTION OF BROWNS CREEK, AIRE DISTRICT, VICTORIA

By Stephen Ryan

BROWNS CREEK: SECTION IN FIRST GULLY



BROWNS CREEK: SECTION IN SECOND GULLY



EXPLANATORY NOTES FOR THE BROWNS CREEK SECTION

Section in First Gully

0-0.6 (0.6m)
Ferruginous calcareous sand, yellow-red in color, quartzose (quartz up to 1mm in size) and micaeous; Iron rich banding, possibly Liesegang?

0.6-0.7 (0.1m)
Calcarenite bed, hard, abundant quartz and shelly fragments.

0.7-1.1 (0.4m)
Ferruginous calcareous sand.

1.1-1.2 (0.1m)
Calcarenite bed

1.2-9.6 (8.4m)
Spirocolpus ("Turritella") clay; well preserved *Spirocolpus*, lesser bivalves, coral and sharks teeth. Interval is sandy at base and glauconitic towards the top. Between 5.5-8.6m the *Spirocolpus* are smaller than below and their numbers decrease, whereas bivalves and coral increase in content. After 8.6m the overall fossil content decreases, with rare *Notostrea* at the top.

9.6-10.2 (0.6m)
Notostrea greensand; up to 70% glauconite, with lesser limonite and quartz.

10.2-11.6 (1.4m)
Glauconitic marl with a thin shell lag at top.

11.6-30.9 (19.3m)
Alternating light grey, grey, dark grey marl separated by thin, hard calcareous bands. The marl on the whole is featureless, however displays varying degrees of weathering. In places it is glauconitic, fossiliferous and bioturbated. The marl is rich in jarosite at the top.

30.9-32.4 (1.5m)
Grey clay, green-brown mottling, weathered

32.4-33.0 (0.6m)
Interlaminated clay and silt, brownish-orange in color.

EXPLANATORY NOTES FOR THE BROWNS CREEK SECTION

Section in Second Gully

0-8.6 (8.6m)
Dark grey marl, clayey at base; interbedded with thin , hard calcareous bands. The calcareous bands at the top of this interval have scoured upper and lower surfaces.

8.6-9.0 (0.4m)
Pale grey clay.

9.0-11.2 (2.2m)
Grey-brown marl, fossiliferous (*Spirocolpus*) in places; iron rich nodules and veins are present.

11.2-11.5 (0.3m)
Dark grey marl, shell fragments, slightly glauconitic and limonitic.

11.5-12.3 (0.8m)
Two thin, hard calcarenite bands separated by grey-brown marl.

12.3-13.8 (1.5m)
Fossiliferous, quartzose, grey marl.

13.8-16.3 (2.5m)
Grey-dark grey sandy marl with *Spirocolpus*; weathered, friable.

16.3-16.7 (0.4m)
Coarse shell lag, consisting of bivalve and *Spirocolpus* fragments with a fine quartz matrix. This unit has an irregular, scoured base and top.

16.7-16.9 (0.2m)
Laminated, fine calcareous sand; cross bedded in places, with an irregular top.

16.9-17.4 (0.5m)
Fossiliferous sandy marl, immediately overlain by a thin calcareous layer.

17.4-19.3 (1.9m)
Sandy marl

19.3-20.8 (1.5m)
Interval of light grey, sandy marl interbedded with four thin calcareous resistant beds.

20.8-23.9 (3.1m)
Light grey- brown, sandy marl with a thin nodular, calcareous hard band at the top.

23.9-25.0 (1.1m)
Pliocene ferruginous, clayey sand.

* These sections were measured by Stephen Ryan, Bruce Simons and Lesley Knight in March 1994 and samples collected by Charles Abele (all geologists with the Geological Survey of Victoria).