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THE MID-TERTIARY FORAMINIFERAL SEQUENCE

ESSO GIPPSLAND SHELF No. 1 WELL.

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## INTRODUCTION

This investigation was conducted on behalf of ESSO Exploration Australia (the operator) and Haematite Explorations Pty. Ltd. (the permit holders). At their request the section has been examined in detail in order to establish a standard foraminiferal sequence for further correlation in the off-shore Gippsland area. The geological staffs of both companies gave the author considerable assistance and complied to requests regarding sampling.

Sample Detail: The well was drilled in 150 foot of water, some 15 miles south of the Gippsland coastline. Rotary cutting samples were submitted from the foot of the surface casing at 780 feet to total depth at 8,701 feet. Rotary cutting contamination was minimal between 780 feet and 4,300 feet apart from the interval 3,050 feet to 3,200 feet. Below 4,300 feet contamination was sporadically heavy down to 8,400 feet. It is noted that the $13\frac{3}{8}$ casing was set at 2,974 feet and the $9\frac{5}{8}$ casing at 6,081 feet. Much of the contamination below 4,300 feet came from the interval 3,400 to 3,500 feet where a "wash out" was noted on the "caliper log".

Eighteen cores were recovered and these were slabbed at the well site, so that a complete section of each core was received. The position of cores from 1,000 feet to 4,000 feet is shown on Fig.1.

The datum for all sample depths was the rotary table given as +31 feet M.S.L. All depths discussed here are those shown on the submitted samples and no adjustment has been made on E-log interpretations etc.

All cores were sampled at 2 foot intervals and cutting samples were examined every 50 feet with reduction of sampling interval where necessary. Normal microfossil preparation techniques were employed. Prepared samples were exhaustively hand-picked for foraminifera and other microfossils. If good faunas were found the fossils were sorted on to grid slides before specific determination of foraminifera was conducted. A comprehensive distribution chart of some 300 species was assembled and this was later abridged to the form shown on Fig.1. Where specific identity was dubious or new species suspected, species numbers were applied and representative specimens were mounted on species slides.

THE FAUNAL SEQUENCE

Cores 1 to 8 contained Tertiary foraminifera and the new species was recorded down to 3,800 feet. The new fauna at 3,800 feet is regarded as uppermost Eocene, so that the Tertiary foraminiferal sequence extends from above 780 feet (= first sample) to the vicinity of 3,800 feet. No older diagnostic faunas were found, although a sample of core 16 (sample interval 6,450-1 feet) contained a sparse fauna of minute, nondescript rotalid forms. This fauna was not found in any other of 10 samples examined from core 16.

In recent years several Tertiary sections in the Gippsland Basin have been studied in considerable detail by foraminiferal workers. Jenkins (1960) studied the Tertiary planktonic foraminifera in the Lakes Entrance Oil Shaft; a vertical, hand-sampled section. Carter (1964) built up a composite sequence, consisting of both outcrop and bore material from the Longford, Bairnsdale and Lakes Entrance areas. Carter's work is an application of his faunal unit scheme, which was based on the Aire Coast sections in Western Victoria (Carter 1958a). Wade (1964) has subsequently discussed the Tertiary planktonic foraminiferal zonation in southern Australia and has co-ordinated the work of Carter and Jenkins.

This previous work provided a firm basis on which to establish a foraminiferal sequence for the Gippsland Shelf No.1 Well. However Carter, Jenkins and Wade all use the first appearance of forms in evolutionary sequence. Theoretically this is the ideal approach as it is in the direction of evolution, that is "up-sequence". But sub-surface sections are drilled "down-sequence". Where rotary cutting have to be used for bio-stratigraphic determination, the first appearance of a species is the only reliable point in its range, because of rotary cutting contamination. This first appearance is in fact the level of extinction of the species in the section. Obviously the "up-sequence" schemes have to be adapted to a "down-sequence" approach.

The author has been working on this problem for several years, especially in regard to the on-shore Gippsland Basin. A less empirical down sequence approach has been tested by using the range and points of fragmentation and bifurcation in a number of linearly evolving species groups. The planktonic series discussed by Wade (l.c.) can be utilized by this approach. The classic Orbulina universa lineage poses difficulties in that the globular shape provides almost maximum bouyancy and may be constantly recirculated as a mud contaminant.

Uvigerinid and bolivinid forms are common in the Gippsland Shelf sequence, though they are not common on-shore, apparently for environmental reasons. Vella (1964)has stressed the significance of linear development within these groups in the New Zealand Tertiary. Similar, though not identical, lineages are recognized in the Gippsland Shelf sequence and these lineages have been detailed. It is thought that the bolivinid and uvigerind lineages will be important factors in correlating subsequent Gippsland off-shore sections.

(i) Gippsland Shelf No.1 Tertiary foraminiferal sequence:-

Vertical distribution of species groups will be discussed down sequence with reference to summarized distribution of selected species as shown on Fig.1.

(a) Planktonic species - Little change in the Globigerina spp. till 3,400 feet where G.euapertura first appears coinciding with the virtual disappearance of G.woodi and G.apertura. G.euapertura clearly develops from G.ampliapertura and this latter form is present below 3,700 feet. The apparent lineage is G.ampliapertura -- G.euapertura -- G.apertura (s.l.). Jenkins (1960) shows that G.woodi replaces G.euapertura, and he includes (pers.comm.) G.apertura (s.l.) within G.woodi. Wade (1964) does not recognize G.woodi and uses G.apertura. The author feels that the two species can be distinguished and that G.woodi is not in the direct G.ampliapertura -- apertura lineage.

The closely related species G.linaperta and G.angiopora appear in association below 3,800 feet. In New Zealand the range of the latter extends higher than that of the former (Hornibrook, 1961).

Most members of Blow's (1956) Globigerinoides triloba - Orbulina universa bioseries are present in the sequence. Orbulina universa is present in cores 1 to 5, whilst O.suturalis is present in cores 6 and 7. Such a distribution would be anticipated. However below core 7 there is no verified recording of G.transitoria, G.bispherica or G.triloba, although Blow shows these species to be ancestral to O.suturalis and would be expected to occur below O.suturalis. As subsequent authors, including Carter, Jenkins and Wade, have substantiated Blow's bioseries, it can only be concluded that the lineage is interrupted in this section before the initial appearance of the mature form of G.triloba. The immature form of G.triloba (either G.triloba immatura or Globigerina woodi connecta Jenkins) is present below 3,080 feet.

Globorotalia spp. do not occur above 1,060 feet. The highest occurring species are mainly the keeled forms referable to G.menardii. G.mayeri is not present above 1,700 feet and G.barisanensis and G.conica is not above 2,300 feet. This is the specific distribution pattern shown by Jenkins (1960) and all these species are within range of Orbulina universa and O. suturalis. Wade (1964) places G.barisanensis and G.menardii moitumbida within the G. fohsi lineage so that the latter replaces the former as is demonstrated in this section. The presence of G.lenguanensis near the top of the range of G.mayeri and well above the top of the range of G.barisanensis is consistent with the findings of Bolli (1957) in Trinidad.

Below 3,400 feet G.opima opima and G.extans are associated with the coarse pored G.testarugosa not present till 3,540 feet and becoming more abundant down the section. These three forms show a relative distribution in agreement with Jenkins (1960).

The Gippsland Shelf sequence reaches the top of the range of Chiloguembelina cubensis at 3,540 feet with rare Guembelitra sp. below 3,800 feet. Although this order of occurrence is similar to that in Trinidad and New Zealand, it is the reverse of Wade's (1964) observations for southern Australia.

(b) Bolivinid species - Four lineage of bolivinids are recognized in the sequence.

One lineage is within a group of elongate forms which exhibit thickening and initial widening of the test, accompanied by peripheral rounding and facial flattening. The ultimate form, Bolivina sp.2 is present down to 2,100 feet and its range overlaps the thinner, more tapered B. sp.8, which is recognized at 1,900 feet. B. sp.8 is not encountered below 2,700 feet. A probably related form, B. sp.12 occurs below 3,300 feet. There is an apparent gap in the lineage.

An outstanding element of the higher part of the sequence is a robust keeled bolivinid referable to Bolivinita, probably comparable with B.compressa of the New Zealand upper Tertiary.

This form is present down to 1,600 feet and a less strongly carinate form, B. sp.2, replaces it. The chambering of B. sp.1 and sp.2 is similar to that of Bolivina sp.2 and the less carinate nature of Bolivinita sp.2 suggests that the Bolivinita sp.2 -- sp. 1 lineage branches off at the fragmentation level (ie. 1,900 to 2,100 feet) of the Bolivina sp.8 -- sp.2 lineage. This Bolivinita lineage is obviously parallel to the B. quadrilatera lineage in New Zealand, but Hornibrook (1953, p.440) suggests that the New Zealand group were immigrants and he does not indicate development from a Bolivina stock.

Bolivina sp.1 is a compressed elongate form with carinate later chambers and raised sutural ribs. Below 1,500 feet, the broader, more triangular form B. sp.4 is present. A similar form, B.sp.9, with elongate ribs occurs below 2,300 feet. These three species are within a definite linear development. The range overlap of species, though broad, is significant.

Below 3,540 feet, the Bolivina pontis to B.anastomosa group is recognized. The former is clearly distinguished below 3,800 feet. The development is similar to that described by Hornibrook (1961) and Vella (1964) from New Zealand. The highest appearance of B.anastomosa is stratigraphically lower than that recorded in New Zealand and slightly lower than other Gippsland Basin sections. Vella (l.c.) shows that B.affiliata is the descendant of B.anastomosa and that the lineage may be surviving as B.robusta. B.affiliata is not recognized in the Gippsland Shelf sequence, but the Bolivina sp.9 to B. sp.1 lineage exhibits similarities to B.robusta.

(c) Uvigerinids - Vella (1961 and 1964) has made an extensive study of New Zealand uvigerinid lineages. Vella's approach is to place the species of one lineage within a distinct higher taxon. This had lead to the erection of a number of new genera and sub-genera within the family Uvigerinidae. This is the modern taxonomic approach, yet Vella's proposed genera and sub-genera have not been generally accepted and probably require greater verification, especially with regard to apertural and internal chamber characteristics. Also Vella stresses the endemic nature of his species. For the above reasons, the author has refrained at this stage from using Vella's nomenclature. The author has generalized the generic concept of Uvigerina, but will attempt to place numbered species within Vella's lineages; that is within his proposed higher taxa.

The Hofkeruva (Trigonouva) group which are common throughout most of the Tertiary section. The first form encountered, Uvigerina sp.1, is elongate and moderately costate. Subsequent forms (down section) are U. sp.2, U. sp.4 and U. sp.8. The latter species is markedly triangular in cross-section and very similar to the New Zealand species "U".miozea. This form appears at 2,300 feet and is still present at 3,000 feet. The general shape and plate like costae of the large U. sp.9 suggests affinity with the New Zealand species "U".dorreeni. As U. sp.9 is present at 3,080 feet and U.sp.8 persists to at least 3,000 feet, then there is apparent disruption of Vella's (1961, Text fig.3) proposed lineage if U.sp.8 = "U".miozea and U.sp.9 ≟ "U".dorreeni.

U.sp.3, U. sp.7 and U.sp.10 are all hispid forms probably within the genus Neouvigerina as explained by Vella. The three Gippsland shelf species do not appear related.

(d) Gyroidinoides - a definite series of the G.zealandica group is recognized in New Zealand. G. sp.1 and G. sp.2 appear unrelated to this group. But below 2,200 feet there is a form, G. sp.3, which resembles G. subzealandica, whilst below 3,080 feet it is replaced by the more angular form G.sp.4 equaling G.zealandica (s.s.). This is the New Zealand order of occurrence although Hornibrook (1961) shows that the ranges of the two species overlap considerably.

(e) Cibicides - Lineages within this group probably exist in the section but have not been studied. Common species down to 2,700 feet include C.cygnorum, C.mediocris, C.subhaidingeri and C.vortex. C.victoriensis is not recorded till 1,500 feet and its presence below 3,080 feet may be due to contamination. C.vortex probably forms a lineage group as a C. 'vortex form B' can be distinguished below 2,400 feet. There is a marked change in the Cibicides fauna at 3,080 feet, with the appearance of C.brevolalis, C.perforatus and C.novozealandica. This change is anticipated from Carter's (1964) and other Gippsland sections.

(f) Elphidium - The order of occurrence of the five recorded species of Elphidium are of significance, as four of them retain the order as recorded by Carter (l.c.), although E. crespinae would be expected to range higher. The fifth species, E.arenea (syn. Discorotalia arenea Hornibrook), is a new recording for Victoria, but is of limited range in New Zealand.

(ii) Biostratigraphic units for Gippsland Shelf No.1 sequence:-

From the above discussion it is now possible to subdivide the sequence into a number of biostratigraphic units, which are comparable with previously established biostratigraphic units, but are not completely equivalent to previous schemes, as by necessity this scheme is a "down sequence" scheme. The biostratigraphic units applied are named zonules as they comprise associations of species of various foraminiferal groups and are intended only for purposes of local correlation.

Zonule A - ? to 1,060 feet: As samples were not collected above 780 feet, the top of this zonule is not known. The complete absence of Globorotalia spp. identifies it but this absence is probably due to environmental factors. The only species restricted to this unit is Uvigerina sp.1 which obviously develops from U. sp.2 in Zonule B.

Zonule B - 1,060 feet to 1,700 feet: The highest ranges of Globorotalia acostaenasis, G.menardii moitumbida, miocenica and praemenardii are within this interval, but these species could easily range higher in other sections. The related species Bolivina sp.2 and B. sp.4 overlap in range. Bolivinita sp.1 is associated with Bolivina sp.1 and characterizes this unit, although both species do occur rarely in the higher unit. The hispid Uvigerina sp.3 appears limited to this unit, and Cibicides victoriensis does not range above the base of the unit.

Zonule C - 1,700 feet to 2,300 feet: Marked by the highest appearance of Globorotalia mayeri and the limited appearance of G.lenguaensis. Within this unit is the fragmentation of the Bolivina sp.8 to sp.1 lineage with bifurcation to the primitive Bolivinita sp.2. The highest appearance of Uvigerina sp.4 overlaps U. sp.2 and the hispid form U. sp.7 does not range above the base of the unit. The ranges of such species as Elphidium pseudoinflatum, Gyroidinoides sp.2 and G. sp.3 extend upwards into this zonule and Textularia sp.3 appears limited to it.

Zonule D - 2,300 feet to 2,700 feet: Characterized by the highest appearances of Globorotalia barisanensis and G.conica. The two cores within this interval contain few Orbulina universa, though higher in the sequence this form is abundant. Bolivina sp.9 is restricted to this unit and clearly develops into Bolivina sp.4. The uvigerinid fauna consists mainly of the hispid Uvigerina sp.7 and the triangular U. sp.8. Elphidium arenea is restricted to this unit.

Zonule E - 2,700 feet to 3,080 feet has sparse faunas throughout, apart from obvious contamination below 3,050 feet. Except for Haplophragmoides cf. paupera, all species recorded occur higher in the sequence. However the zonule criteron is established on core samples which contain Orbulina suturalis without associated O.universa. Just above this zonule, core 5 contains rare O.universa, whilst O.suturalis is more common. Thus 2,700 feet is taken as the level of initial appearance of O.universa.

Haplophragmoides spp. are common within the zonule.

A significant feature of this zonule is the presence of worn Lepidocyclina sp. Gypsina sp. and Amphistegina sp., with decayed fragments of bryozoa. The sediment is a sandy one and is not comparable with the typical Victorian lepidocyclinal limestones (ex. the Glencoe Limestone of Gippsland). Furthermore Carter (1964) demonstrates that Orbulina suturalis appears above and not in association with Lepidocyclina sp. in Victoria. It is considered that these Lepidocyclina and other larger foraminifera are derived.

Zonule F and G are missing in this sequence. As already stated the Globigerinoides triloba -- Orbulina universa bioseries is interrupted before the appearance of the mature form of G.triloba and is recommended with O.suturalis. The two significant missing events are the appearance (up sequence) of G.triloba and of G.bispherica. It is also noted that several bolivinid and uvigerinid lineages appear to be interrupted. Moreover fresh specimens of Lepidocyclina sp. and other larger foraminifera are not present, although they would be expected immediately below O.suturalis.

The absence of the expected Zonules F and G indicates a hiatus within the sequence.

Zonule H - 3,080 feet to 3,400 feet - Despite contamination down to 3,200 feet, the fauna is impressively different. Globigerina apertura, G.woodi, are still present with immature and dubious specimens of Globigerinoides triloba. At the top of and within the zonule, such forms as Cibicides brevolalis, C.perforatus, C.novozealandica, Uvigerina sp.9, U. sp.10, U.sp.11, Astrononion centroplax and Anomalinoides vitrinoda. Arenaceous species are common with Textularia spp., Dorthia spp., Haplophragmoides spp. and Karreriella sp. The appearance of Karreriella sp. and Haplophragmoides rotundata within the unit may be a biostratigraphic rather than a purely environmental feature, as these two species have not been noted at relatively higher levels in Gippsland sections.

Zonule I - 3,400 feet to 3,540 feet - Globigerina eurapertura is positively identified at 3,400 feet and G.apertura and G.woodi are both extremely rare. Globorotalia opima opima and G.extans are rare though important elements of the planktonic fauna. The benthonic fauna is similar to that of Zonule H, except for the presence of Vaginulinopsis gippslandicus and the arenaceous Vulvulina sp. (probably referable to the New Zealand V.granulosa). There is a rich arenaceous fauna.

Zonule J - 3,540 feet to 3,800 feet - A strikingly different fauna due to the small size of specimens when compared with the robust Zonule I fauna. The planktonic elements are similar to Zonule H apart from the presence of Globorotalia testarugosa and Chiloguembelina cubensis. There is a notable reduction in specimen size of the benthonic species which also occur in the two preceding zonules. Arenaceous species are rare. The highest occurrence of Bolivina anastomosa and the arenaceous Bolivinopsis cubensis are noted at 3,540 feet.

Zonule K - 3,800 feet to ? - Fauna generally similar to Zonule J, but mixtures of Globigerina eurapertura with the ancestral form G.ampliapertura and of Bolivina anastomosa with the ancestral form B.pontis, indicate specific fragmentation in these two lineages. This level also contains the highest appearance of the planktonic Globigerina angipora and G.linaperta as well as the rare occurrence of Guembelitra sp.

Below 3,800 feet - No new species were found below this level and all cores were barren of foraminifera. Foraminifera were found sporadically in cutting samples below 4,400 feet to 6,000 feet, but all species are referable to those found in Zonule H and I. Obviously these foraminifera are contamination, and the fact that Vulvulina sp. and Vaginulinopsis gippslandicus are present suggests that the contamination came from the vicinity of 3,500 feet.

CORRELATION OF GIPPSLAND SHELF SEQUENCE

(i) Biostratigraphic correlation with other Victorian sequences:

Comparison can now be discussed between the Gippsland Shelf No. 1 zonule scheme and the biostratigraphic schemes of Carter (1958 and 1964), Jenkins (1960) and Wade (1964). This comparison is summarized on Fig.1.

Zonule A - appears to be in a higher position than the top unit of either Jenkins' or Carter's schemes. In fact none of the proposed schemes have a defined top. The fauna of Zonule A is probably environmentally controlled.

Zonule B - is within Carter's definition of Faunal Unit 11 as it contains abundant planktonic fauna. The presence of Globorotalia menardii moitumida and miocenica with the highest appearance of G.menardii praemenardii within the Zonule and G.mayeri at its base, is indicative of Jenkins' G.menardii moitumida Zone (Zone 11).

Zonule C - the highest range of Jenkins' G.mayeri supports comparison with Jenkins' G.mayeri Zone (Zone 10). The occurrence of G.lenguaensis implies that this is also Wade's G.mayeri Zone.

Zonule D - the base of the Zonule is designated to be at the initial appearance of Orbulina universa, thus this unit corresponds with the defined base of Carter's Faunal Unit 11. This unit is the equivalent of both Jenkins' and Wade's O.universa Zone and the presence of Globorotalia conica and G.barisanensis are in agreement with Jenkins' findings.

Zonule E - The presence of O.suturalis without O.universa is the criterion of Carter's Faunal Unit 10 and Wade's suturalis Zone. This Zonule is probably within Jenkins' Zones 8 and 7. At this stage in the sequence, Jenkins' zonation is too subtle to be achieved in a normally drilled sequence.

Zonules F and G - missing in the Gippsland Shelf sequence, but if present would contain the events of Wade's quadrilobatus quadrilobatus Zone (= Zonule G) and bisphericus Zone (= Zonule F). Carter has three units (9 to 7) and Jenkins has 4 (7 to 4) in this biostratigraphic interval, but in view of Wade's findings, it is felt that only two units should be reserved in this down-sequence scheme. Carter diagnoses Faunal Unit 9 by the larger foraminiferal association (including Lepidocyclina) and clearly demonstrates its position relative to the planktonic sequence. The author considers the association as one of the benthonic markers of Zonule F.

Zonule H - the apparent absence of Globigerinoides triloba but the presence of immature forms (?Globigerina woodi immatura) with G.woodi is indicative of Jenkins' G.woodi Zone. This Zone is the equivalent of Carter's Faunal Unit 6.

Zonule I - The highest appearance of Globorotalia extans and G.opima opima with the positive appearance of G.euapertura equates this with Jenkins' Globoquadrina dehiscens Zone (Zone 2). This is the equivalent of Faunal Unit 5, but Carter's main indicator, the adherent Victoriella conoidea is not present in this sequence.

Zonule J - Chiloguembelina cubensis without Globigerina linaperta is the planktonic criterion of Carter's Faunal Unit 4.

Although Carter did not positively identify this unit in Gippsland, he suspected its presence and lately Hocking and Taylor (1964) have recognized it in limited areas. The highest appearance of Globorotalia testarugosa conforms with Jenkins lowest zone, but Zonule J probably represents a larger biostratigraphic interval than this zone. Jenkins recorded only 5 specimens of G.testarugosa at the base of his Lakes Entrance Oil Shaft seouence, suggesting that this was the extinction level of the species.

Zonule K - Carter's Faunal Unit 3 is at the top of the range of Globigerina linaperta so that Zonule K is probably at the top of Faunal Unit 3.

(ii) Correlation with Victorian Tertiary Stages:

Carter (1964) has shown the relationship of his faunal units to a revised Victorian Tertiary Stage Classification. As the Gippsland Shelf sequence zonules are equated with Carter's faunal units, then the zonules are made to fit the classification, although the author does not consider them to have any significance in discussion or future correlation of the sequence. For instance Carter differentiates the Mitchellian from the underlying Bairnsdalian on a faunal change which resulted from shallowing water. With regard to water depth, one would expect "facies step out" during mid-Tertiary times from the present on-shore to off-shore areas. As this is evident in the recognized Bairnsdalian ( = Zonules D and ?C) it would be expected in the Mitchellian. Recognition of the Mitchellian can only be achieved by determining upper Miocene. Direct faunal correlation is not possible.

Crespin's (1943) stage classification for the Gippsland Basin appears to be a more workable one, but is dependent on facies without real biostratigraphic consideration. In the

Gippsland Basin, Crespin's work did not suggest time-transgressive sedimentation, whilst an application of Carter's faunal unit scheme did, as shown by Hocking and Taylor (1964). It is evident that Crespin's scheme is in reality a rock stratigraphic one and will be discussed later as such.

(iii) Intercontinental correlation:

The sequence can be discussed in terms of accepted world-wide division of the Tertiary period. Wade's (1964) thorough study of both the actual faunas and the massive literature, has placed the southern Australian plankonic sequence within the framework of the European Standard Stage Classification of the Tertiary. More recent overseas literature supports her contentions. Discussion on these matters will be limited to comment on the Gippsland Shelf sequence.

Following Wade's evidence, Zonule K is obviously at the top of the Eocene, Zonule J is lowermost Oligocene, whilst Zonule I occupies the rest of the Oligocene (Chattian). Glaessner (1959) and Wade (1964) both argue that Carter's Faunal Unit 6 can be correlated with the Aquitanian (lowermost Miocene) on its relative position in the planktonic sequence and thus the Oligocene/Miocene boundary is below the general emergence of the distinct "Globigerinoides form". Zonule H is considered as basal Miocene.

The absence of Wade's quadrilobatus quadrilobatus Zone ( = Zonule G) and bisphericus Zone (= Zonule G) indicates the absence in the sequence of most of the lower Miocene (Burdigalian). Wade places her suturalis and universa Zones within the Helvetian and her "mayeri" Zone within the Tortonian. Thus Zonules E to C are middle Miocene. Wade's mayeri Zone is equated with Bolli's (1957) mayeri Zone, which marks the highest appearance of Globorotalia mayeri and the incoming of G.lenguaensis. The top of Zonule C is marked by the highest appearance of G.mayeri and the presence of G.lenguanensis. Therefore Zonules B and A are probably within Bolli's menardii Zone and are taken to represent the upper Miocene.

From studies of Carter, Jenkins and Wade, it can be concluded that a marine Tertiary sequence is present from the upper Eocene to at least the middle Miocene in southern Australia. In the case of the Gippsland Shelf No.1 Well a sequence has been shown which extends from the uppermost Eocene to highest Miocene, with a break during the lower Miocene.

(iv) Trans-Tasman correlation:

The proximity of New Zealand would suggest that correlation should be attempted with the Gippsland Shelf sequence. Jenkins (pers.comm.) is currently working on a correlation between the New Zealand Tertiary planktonic sequence and that of the Lakes Entrance Oil Shaft. At this stage comment is premature, but certain features are obvious. It would appear from the descriptions of Hornibrook (1961) and Vella (1964) that Zonules K and J contain Whaingaroan planktonic and benthonic faunas. A characteristic planktonic species of the Whaingaroan is Globigerina reticulata which may be con-specific with Globorotalia testarugosa. Jenkins (1963) places the Whaingaroan astride the Eocene/Oligocene boundary, which is the already correlated position of Zonules K and J. Similarities also exist between the planktonic faunas of Zonule H and the Waitakian Stage which Jenkins (1964) suggests as the base of the Miocene.

Another correlation is the fact that the New Zealand upper Miocene is characterized by the entry of Bolivinita spp. of the B.quadrilatera Gp. Hornibrook (1958) points out that this event occurs slightly earlier in New Guinea. However the presence of Bolivinita sp.1 does correlate Zonule B with the Tongaporutuan Stage of New Zealand.

DEPOSITIONAL HISTORY

(i) Depositional environments:

The generic and specific content of the Gippsland Shelf foraminiferal sequence has permitted biostratigraphic break down but also gives some key to the depositional environment at the time of sedimentation, especially if all facies (bio and litho) are interpreted together. Detailed sedimentology has not been conducted on the sediments, so that a more complete story must await this work. The palaeoecological significance of the faunas in the zonules will be discussed in ascending order.

Zonules K and J (uppermost Eocene to lower Oligocene): This is within a sandy interval which contains thin bands of carbonaceous material (lignite and/or brown coal). Only sporadic faunas are recorded, but, when present, specimens are fairly abundant. The outstanding feature is the small size of the specimens and the dominance of planktonic species. One thousand specimens were counted in each of three samples with regard to the planktonic/benthonic foraminiferal ratio. The results were: at 3,560-3,570 feet = 70% : at 3,730 to 3,740 feet = 83% : at 3,805 to 3,810 feet = 87%. Throughout the zonule the average size of specimens was less than .25mm. The benthonic fauna consisted predominantly of uvigerinids and bolivinids with a small percentage of arenaceous forms.

Such a high percentage of planktonic forms would suggest an open ocean environment, whilst bolivinid and uvigerinid forms are fairly dominant benthonic constituents of outer shelf deposits. These conclusions do not account for the nature of the sediment, nor the abnormally small size of individual specimens. The explanation is probably that the faunas are "displaced", in that the tests have been washed into an alien environment. The sediments suggest shallow water, marginal marine conditions (lagoonal or swamp). If this environment was separated from the sea by a narrow barrier, then any marked sea-level rise (due to storms or abnormal tides) could cause flooding by marine waters. Strong on-shore winds would bring in the oceanic plankton and could cause turbulence on the sea floor, suspending empty benthonic tests as described by Murray (1965). Under such conditions Murray (l.c.) shows size sorting operates on the foraminiferal tests, thus accounting for the small specimen size in the faunas. The sporadic distribution of the faunas within the interval indicates that the marine connections were not constant throughout the interval. This contention is supported by the lack of any obviously endemic fauna, which would not be established if sea water was diluted by coastal run-off, when the cause of marine flooding desisted. Such conditions exist today in the lagoons on the Gippsland seaboard.

It should be recorded that the delicate tests and the fairly homogenous nature of the fauna does not indicate that it is reworked. The "displacement" is environmental and not stratigraphic, which is substantiated by previous discussions which show that the faunas are not misplaced in the Victorian Tertiary planktonic sequence.

Zonules I and H (upper Oligocene and lowest Miocene):

The sediment is a marl, glauconitic at the base, with a marked faunal change. Planktonic, arenaceous and lagenid species with robust species of Cibicides are the dominant elements. Even at the base of the interval the arenaceous forms reflect an absence of quartz sand as their tests are composed of smaller particle size material. Fairly shallow water conditions, open to the ocean are evident with slow sediment accumulation.

Zonule E (middle Miocene):

Calcareous sandstone with sparse arenaceous and miliolid faunas with occasional planktonic species. Obviously a shallow water swiftly accumulating sediment.

Zonule D (middle to upper Miocene):

Sand content decreases up the section, with marls and limestones present above 2,500 feet. With the decrease in sand the faunas are larger and the planktonic percentage increases as does the percentage of uvigerinid and bolivinid forms. A deepening of the depositional environment is suspected.

Zonules C and B (middle to upper Miocene).

Faunas and sediment similar to that at the top of Zonule D. Shelf conditions are indicated.

Zonule A (upper Miocene).

The sediments are mainly calcareous, but are richly bryozoal. The percentage of planktonic forms is reduced with a marked absence of *Globorotalia* spp. There is an increase of miliolid and arenaceous forms (virtually absent in Zonules C and B). Shallowing water is evident. The environment is probably an inner shelf one, but certainly not littoral.

Biohermal accumulations are not present within sequence.

(ii) The sequence of depositional events:

This is illustrated on Fig.2. for the Gippsland Shelf Tertiary foraminiferal sequence (from 3,800 feet to 780 feet).

The base of the sequence is of uppermost Eocene age. Sedimentation took place in a marginal marine environment (ex. lagoons) with periodic marine ingressions. During the Oligocene there was a general marine transgression covering the depositional area with shallow water. The fine grained nature of the marl and the formation of glauconite suggests slow sedimentation and isolation from sources of detrital material. This transgression was in fact a basin wide event which extended well into the present on-shore area (probable source areas). During the lower Miocene there was a hiatus which has not yet been recognized on-shore. Sedimentation was resumed in the middle Miocene with the deposition of sand and detrital limestone material. The limestone detritus contains worn bryozoa and larger foraminifera and is suspected to have been reworked from the Glencoe Limestone (refer Carter, 1964) of the Longford District. There was a gradual deepening of water during the middle Miocene, with an apparent reversal of the trend in the upper Miocene. The post Miocene history is not known due to lack of samples.

(iii) Palaeogeography:

Throughout this foraminiferal sequence the climate appears to have been a temperate one with current circulation as is today. This is the opinion of Wade (1964) for southern Australia. Reed (1965) on the study of the Heywood No.10 bore (western Victoria) feels that planktonic faunas described by Jenkins (1960) indicate warmer water conditions for Gippsland than those of western Victoria. Reed's conclusions are not borne out by the author's study of any Victorian Tertiary sequence, and certainly not in the Gippsland Shelf sequence, where the combined percentage of Globoquadrina dehiscens and keeled Globorotalia spp. is never more than 5% of the total planktonic fauna in any sample. There are inherent differences between the western Victorian and Gippsland mid-Tertiary faunas, but the author believes these to be palaeogeographic, as Hopkins's (1965) information does suggest that Bass Strait may not have been a "through-way" between the Otway Basin (western Victoria) and the Gippsland Basin during mid-Tertiary times. Reed's (l.c.) Fig.3 clearly shows that "west wind drift" currents moved south of Tasmania and that the Gippsland Basin would have been fed only by the "east Australian current" which also influences the west coast of

The "Baragwanath Anticline" and the "Gippsland Shelf Structure" are roughly parallel and their axes some 30 miles apart, yet sedimentation took place on them at different times. For instance lepidocyclinal limestones were deposited on the "Baragwanath Anticline" (as are seen at Brock's Quarry) at a time when a hiatus is evident on the "Gippsland Shelf Structure". Immediately following this, reworked lepidocyclinal limestone is present on the "Gippsland Shelf Structure" during a hiatus on the "Baragwanath Structure". Other differences are illustrated on Fig.2. It must be pointed out that Fig.2 illustrates only the differences between the two structures and is not intended to imply these features in any other part of the Gippsland Basin. The depositional environment has been drawn relative to sea level on the basis of information discussed here and on unpublished work.

Envisaging these two structures as vertically moving blocks (as on Fig.2), then the direction of movement must have been opposed throughout the period in order to account for differences in the Tertiary sequence on each structure.

With regard to litholigcal correlation within the Gippsland Basin, the following conclusion can be drawn on facies similarities.

The facies which contains Zonules K and J are almost identical to those of the sandy unit at the base of the Lakes Entrance Formation in the Lake Wellington Trough (Hocking and Taylor, 1964). This unit is the time equivalent of the Greensand and Colquhoun Gravel Members in the Lakes Entrance area, although the facies are slightly different due to thicker accumulations of glauconite in the latter, which the author regards as an "estuarine backwater".

The faunal elements of Zonules H and I are identical with those of Crespin's (1943) "Janjukian faunas" of the Gippsland Basin and especially of the Micaceous Marl Member of the Lakes

Entrance Formation in the type sections. Crespin's "zonal" foraminifera of her "Janjukian" is Cyclammina incisa (= Haplophragmoides cf. incisa) and the fauna is characterized by arenaceous species. This is one of the faults in Crespin's Stage classification as here "zonal features" are really facies features. Yet it enables us to quickly identify the facies of the Micaceous Marl. The author would place the top of the Lakes Entrance Formation at 3,080 feet in the Gippsland Shelf Well. The base of the Lakes Entrance Formation (sandy unit) is difficult to pick because it is a sand on sand contact with the top of Latrobe Valley Coal Measures and only cuttings are available, but it must be below 3,540 feet. Hocking and Taylor (l.c.) suspected intertonguing of this contact in the Wurruk Wurruk bore, but Carter (1964) gives evidence of erosion at this contact in Woodside No.2 well.

The calcareous sandstone (3,080 to 2,600 feet approx.) containing detrital limestone material is not known elsewhere in the Gippsland Basin but is here explained on structural grounds. It could be considered as a new member of the Gippsland Limestone. The rest of the section to 780 feet is regarded as a deeper water facies of the Gippsland Limestone. Its top is younger than that of the on-shore unit but this is obvious because of "facies stepping out".

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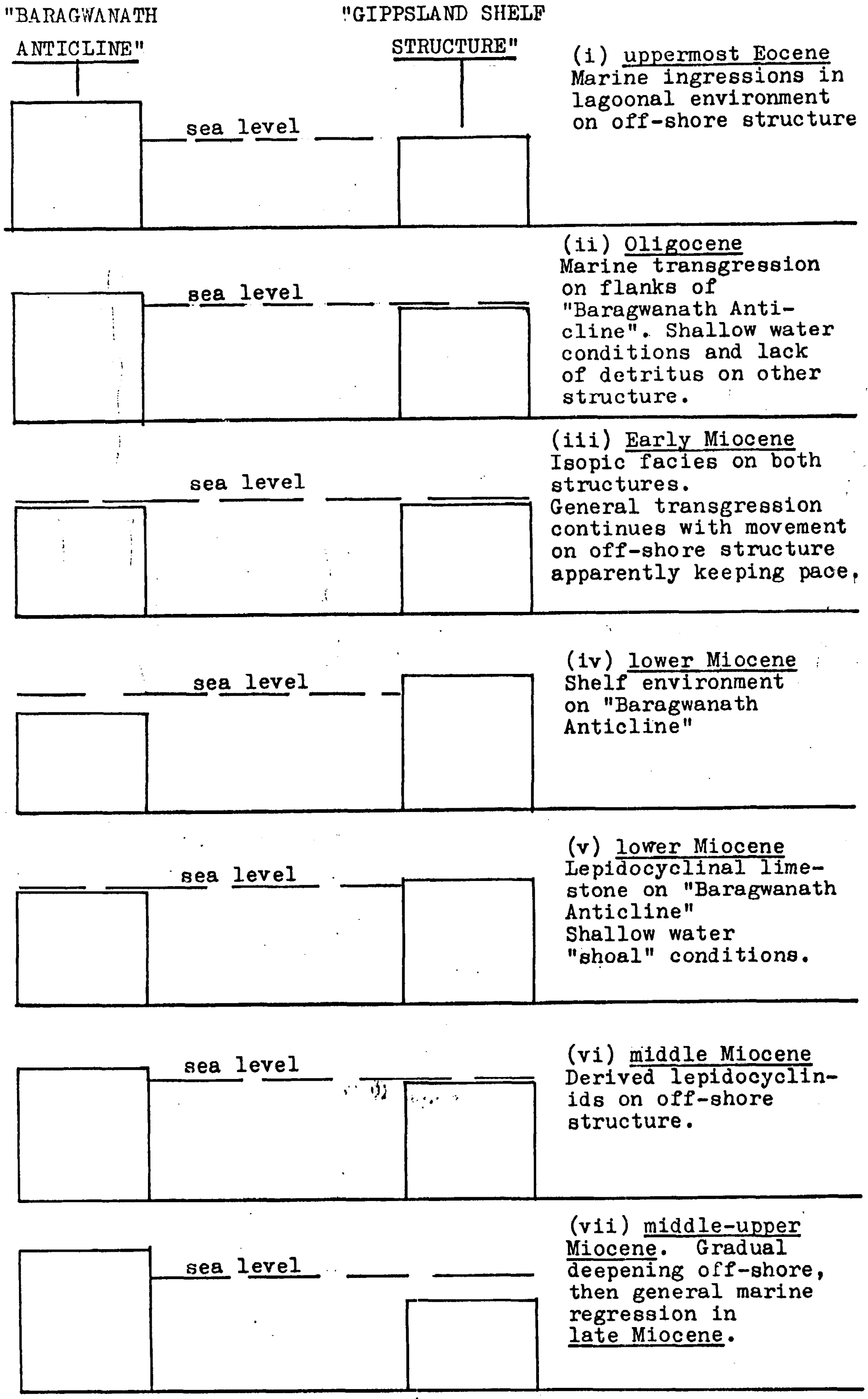


FIG. 2 - DIAGRAMMATIC COMPARISON OF STRATIGRAPHIC AND ENVIRONMENTAL SITUATIONS ON BARAGWANATH ANTICLINE AND OFF-SHORE STRUCTURE DURING MID-TERTIARY.