

PALEOGENE PLANKTONIC FORAMINIFERA OF NEW ZEALAND AND THE AUSTRAL REGION

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ABSTRACT

The 103 documented Paleogene planktonic foraminifera from 21 New Zealand sections which were previously divided into 14 zones have been further subdivided into 26 subzones and a correlation is attempted with Trinidad. A correlation of the following Austral regions is also made: 9 southern Australian sequences, a composite New Zealand sequence based on 21 sections, 4 deep-sea cores from the South Pacific, and 2 sequences from Argentina and 1 from Chile. A detailed examination is undertaken of the upper Eocene-lower Oligocene faunas in order to determine the accurate placement of the Eocene-Oligocene boundary. Although there are a number of taxa common to the Boreal, Tropical-subtropical, and Austral Belts, some of their extinc-

tion levels appear to be diachronous. A recorded drop in sea-water temperature of 9°C from oxygen isotope analyses in the Upper Eocene of New Zealand effectively reduced species diversity and was the probable cause of the diachronous nature of the initial appearances and extinctions. It is postulated that the cooling probably began in Antarctica in the upper Eocene, spreading northwards to the New Zealand region, then the cooling affected the already potentially cooler Boreal region in the lowermost Oligocene and finally lowered the temperature of the warmer Tropical-subtropical Belt later in the lower Oligocene. A time sequential paleo-biogeographic model of the upper Eocene-lower Oligocene planktonic foraminifera is presented.

INTRODUCTION

When the difficulties of interpreting worldwide Paleogene biostratigraphy are viewed from New Zealand situated in the remote middle latitudes of the southern hemisphere, there appears to be a different perspective and attitude towards the existing problems. Because of the distances involved, difficulties of correlation with Europe by biostratigraphic methods are at their maximum in New Zealand and southeastern Australia. Also, because of faunal differences, the Austral Paleogene is difficult to correlate accurately with the Tropical-subtropical Belt.

According to the most recent estimation by Berggren (1972), the Paleogene boundaries are dated as follows: (a) Mesozoic-Cenozoic at 65 my, (b) Paleocene-

Eocene at 53.5 my, (c) Eocene-Oligocene at 37.5 my, and (d) the Oligocene-Miocene at 22.5 my. During the 42.5 my of the Paleogene, the Austral planktonic foraminiferal fauna was generally dominated by cosmopolitan taxa with brief incursions during the Eocene of the mainly tropical forms such as *Hantkenina* Cushman while others such as *Cribohantkenina* Thalman, *Clavigerinella* Bolli, Loeblich, and Tappan, and *Porticulasphaera mexicana* (Cushman) remained in the warmer waters to the North of New Zealand.

It is intended to broadly discuss the New Zealand Paleogene planktonic foraminiferal fauna and zonation, its correlation with Australia and other Austral records and also with Trinidad. In order to focus attention on some of the difficulties of correlation, a detailed exami-

TABLE 1

New Zealand planktonic foraminiferal zones documented from 21 stratigraphic sections.

EPOCHS	PLANKTONIC FORAMINIFERAL ZONES	STRATIGRAPHIC SECTIONS
OLIGOCENE	<i>G.(G.) woodi woodi</i> <i>G. deniscens</i> <i>G.(G.) eupertura</i> <i>G.(G.) anguliporoides anguliporoides</i> <i>G.(G.) brevis</i>	MIDDLE WAIPARA RIVER TE URI STREAM WAIPAWA HAMPDEN BEACH AND MOERAKI KAKANUI RIVER, KIA ORA KAIATA CREEK PORT ELIZABETH KAKANUI RIVER EVERETT'S QUARRY TAYLOR'S QUARRY "EARTHQUAKES" DUNTRON KOKOAMU CLIFF OTIAKE STREAM OTIAKE TRIG. Z LONDON CK. NORTH BRANCH LONDON CK. WATER-RACE FLUME RAGLAN HARBOUR BLUECLIFFS MUDDY CREEK PARENGARENGA HARBOUR
Eocene	<i>G.(S.) linaperta</i> <i>G.(T.) inconspicua</i> <i>G.(G.) index index</i> <i>P. primitiva</i>	
L	<i>G.(M.) crater crater</i>	
	<i>G. wilcoxensis</i>	
PALEOCENE	<i>G.(S.) triloculinooides</i> <i>G.(G.) pauciloculata</i>	

nation of the Eocene-Oligocene boundary is undertaken and a postulated time-sequential model is proposed for the Upper Eocene-Lower Oligocene planktonic faunas.

The writer has previously recorded the stratigraphic ranges of 103 species and subspecies including new

species of planktonic foraminifera (Jenkins, 1966, 1971) from 21 Paleogene stratigraphic sections (table 1) which appear from rock sections to cover all the New Zealand Paleogene apart from a faunal break in the lowermost Paleocene and another possible hiatus positioned at about the middle Paleocene (table 2). Later, all the taxa were illustrated and discussed (Jenkins, 1971). The Paleogene was divided into 14 zones and now these zones have been subdivided into 26 subzones (table 2).

The writer has previously discussed the value of subzones in biostratigraphy, noting their potential in local correlations (Jenkins, 1970) with some of the Paleocene subzones apparently having only a limited value within parts of New Zealand. As, for example, the *Globorotalia* (*Morozovella*) *velascoensis* Subzone is only represented by the *G. (M.) velascoensis* fauna in the Middle Waipara River section of the South Island (Jenkins, 1964, 1971). Even so, from published data the fauna is very widespread and was documented initially in Trinidad by Bolli (1957a).

There are some species which seem to have been restricted to the Austral Belt, which has an arbitrary northern boundary at 30° S. latitude but detailed examination has revealed differences between faunas of New Zealand and southeastern Australia, west of Bass Strait. These former species include Austral taxa or alternatively the species have not as yet been recorded in the Tropical-subtropical Belt because they are too rare. It is therefore postulated that taxa found in both Austral and Boreal Belts must have had some inter-connection through the lower latitudes and these taxa will be found in the Tropical-subtropical Belt. *Globorotalia* (*Turborotalia*) *munda* Jenkins is an example, first recorded in the lower Oligocene of New Zealand (Jenkins, 1966), later by Ludbrook and Lindsay (1969) in the Oligocene of South Australia and then by Berggren (1969) in the Boreal Oligocene who stated that it "has been found to be a useful guide to the Rupelian of northern Europe."

PALEOGENE PALEOGRAPHIC SETTING

Two possibilities must be entertained: (1) New Zealand and Australia have remained in the same geographic position as at present, or (2) more realistically the two countries have moved in a general northward direction away from Antarctica during the Paleogene due to sea-floor-spreading and resultant continental drift (text fig. 1). The latter possibility has been discussed by Kennett *et al.* (1972).

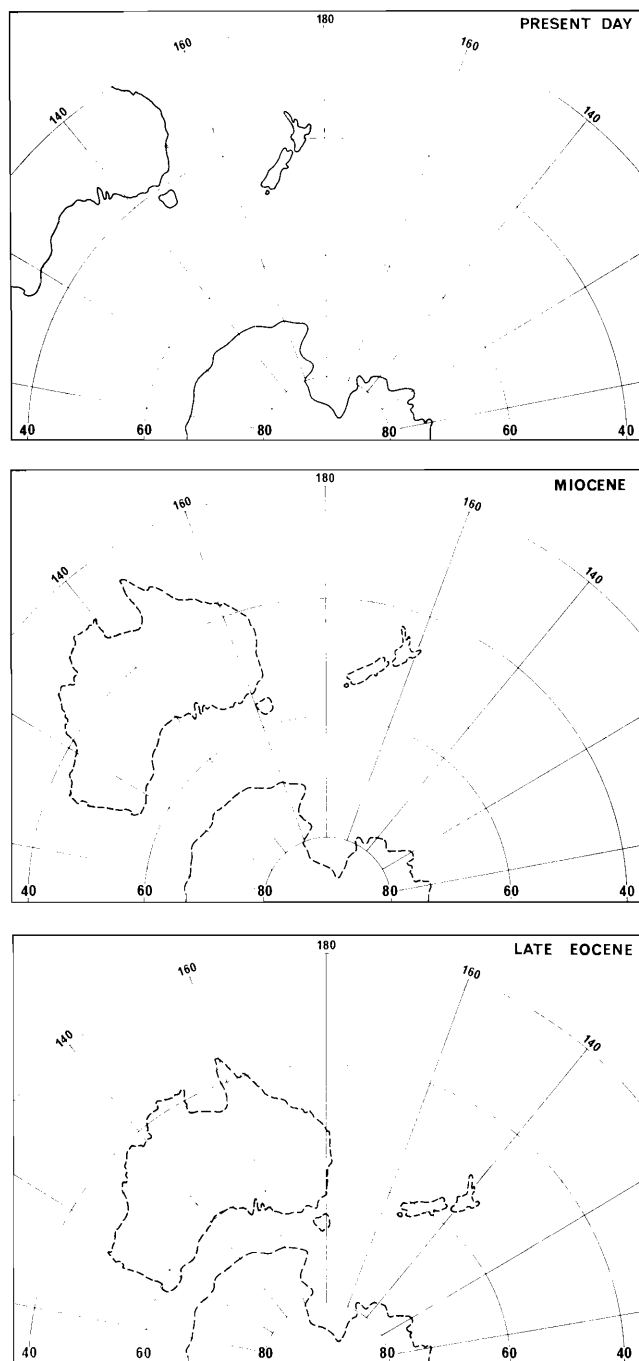
NEW ZEALAND PALEOGENE PLANKTONIC FORAMINIFERA

TABLE 2

New Zealand Paleogene planktonic foraminiferal zones, sub-zones, and calcareous nannofossil zones correlated with Trinidad planktonic foraminiferal zones.

NEW ZEALAND PALEOGENE PLANKTONIC FORAMINIFERAL ZONES AND SUBZONES		DEFINITIONS OF ZONAL AND SUBZONAL BOUNDARIES IA INITIAL APPEARANCE EXT EXTINCTION	CALCAREOUS NANNOPLANKTON ZONES OF NEW ZEALAND (AFTER EDWARDS, 1971)	EXTINCTIONS AND INITIAL APPEARANCES OF PLANKTONIC FORAMINIFERA COMMON TO NEW ZEALAND AND TRINIDAD	TRINIDAD PLANKTONIC FORAMINIFERAL ZONES (AFTER BOLL, 1957 G, BC)
<i>Globigerina</i> (G) <i>woodi connecta</i> (part)		IA. G (G) <i>woodi connecta</i>	INSUFFICIENT DATA		
<i>Globigerina</i> (G) <i>woodi woodi</i>	<i>Globigerina</i> (G) <i>woodi woodi</i> / <i>Globorotalia</i> (T) <i>nana semivera</i>	EXT. G (T) cf <i>obesa</i>			<i>G. ciperensis</i> <i>ciperensis</i>
	<i>Globorotalia</i> (T) cf <i>obesa</i>	IA. G (G) <i>woodi woodi</i>			
<i>Globaquadrina</i> <i>dehiscens</i>	<i>Globigerina</i> (G) <i>brazieri</i>	IA. G (G) <i>brazieri</i>	<i>Zygrabliithus</i> <i>bijugatus</i>	G (T) <i>opima</i> , EXT.	
	<i>Globaquadrina dehiscens</i> / <i>Globigerina</i> (G) <i>bradyi</i>	IA. G. <i>dehiscens</i>	<i>Discoaster</i> <i>delondrei</i>		
<i>Globigerina</i> (G) <i>eupertura</i>	<i>Globigerina</i> (G) <i>eupertura</i> / <i>Globigerina</i> (G) <i>bulloides</i>	EXT. G. <i>cubensis</i>	<i>Syracosphaera</i> <i>clathrata</i>		G (G) <i>opima</i>
	<i>Globigerina</i> (G) <i>labiocrassata</i>	EXT. G (S) <i>angiparoides</i> <i>angiparoides</i>	<i>Cyclacoccolithus</i> <i>neogammation</i>		
<i>Globigerina</i> (S) <i>angiparoides</i>	<i>Globigerina</i> (G) <i>ciperensis</i> <i>angustumbilicata</i>	IA. G (G) <i>ciperensis</i> <i>angustumbilicata</i>	<i>Reticulofenestra</i> <i>placamarpha</i>	G (T) <i>opima</i> , IA.	G (G) <i>ampliapertura</i> - <i>G. cerroazulensis</i>
	<i>Globigerina</i> (G) <i>ampliapertura</i>	EXT. G (G) <i>brevis</i>	<i>Blackites</i> <i>rectus</i>	G (G) <i>seminvoluta</i> , EXT.	
<i>Globigerina</i> (G) <i>brevis</i>	<i>Globigerina</i> (G) <i>brevis</i> / <i>Globorotalia</i> (T) <i>gemma</i>	EXT. G (G) <i>seminvoluta</i>	<i>Reticulofenestra</i> <i>oamaruensis</i>		G (G) <i>seminvoluta</i>
	<i>Globigerina</i> (G) <i>brevis</i>	IA. G (G) <i>brevis</i>	<i>Discoaster</i> <i>sapianensis</i>		<i>T. rhari</i>
<i>Globigerina</i> (S) <i>linaperta</i>	<i>Globorotalia</i> (T) <i>nana nana</i>	IA. G (T) <i>nana nana</i>	<i>Isamolithus</i> <i>recurvus</i>	G (T) <i>nana nana</i> , IA.	
	<i>Hankeneria alabamensis</i>	EXT. G (T) <i>inconspicua</i> <i>inconspicua</i>	<i>Chiasmolithus</i> <i>oamaruensis</i>		G. <i>beckmanni</i>
<i>Globorotalia</i> (T) <i>inconspicua</i>	<i>Truncatolites</i> <i>collected</i>	EXT. T. <i>collected</i>	<i>Reticulofenestra</i> <i>bisecta</i>		G. <i>lenneri</i>
		IA. G. <i>cubensis</i>	<i>Discoaster</i> <i>tanadifer</i>		
<i>Globigerapsis</i> (G) <i>index index</i>	<i>Globigerapsis</i> (G) <i>index index</i> / <i>Globorotalia</i> (T) <i>aculeata aculeata</i>	EXT. G (A) <i>saldadoensis</i>	<i>Discoaster</i> <i>distinctus</i>		G (G) <i>rugieri</i>
	<i>Globigerapsis</i> (G) <i>index index</i> / <i>Globorotalia</i> (A) <i>saldadoensis</i>	IA. G (G) <i>index index</i>	<i>Reticulofenestra</i> <i>hampdenensis</i>	G (G) <i>index index</i> , A	
<i>Pseudoglobaquadrina</i> <i>primitiva</i>	G (S) <i>angiparoides minima</i>	IA. G (A) <i>angiparoides minima</i>	<i>Cniphragmalithus</i> <i>cristatus</i>		H. <i>aragonensis</i>
	<i>Globorotalia</i> (T) <i>australiformis</i>	EXT. G (P) <i>australiformis</i>	<i>Discoaster</i> <i>elegans</i>		G. <i>palmeri</i>
	<i>Globorotalia</i> (M) <i>crater crater</i> / <i>Globigerina</i> (G) <i>boweri</i>	EXT. G (M) <i>crater crater</i>	<i>Reticulofenestra</i> <i>dicyclada</i>		G (M) <i>aragonensis</i>
<i>Globorotalia</i> (M) <i>crater crater</i>	<i>Globorotalia</i> (M) <i>dolabrata</i>	EXT. G (M) <i>dolabrata</i>	<i>Discoaster</i> <i>lodaensis</i>		
		IA. G (M) <i>crater crater</i>	<i>Chiasmolithus</i> <i>grandis</i>	G (M) <i>gracilis</i> , EXT.	G (M) <i>formosa</i> <i>formosa</i>
<i>Globanomalina</i> <i>wilcoxensis</i>	<i>Globanomalina wilcoxensis</i> / <i>Globorotalia</i> (M) <i>aequa rex</i>	IA. G. <i>wilcoxensis</i>	<i>Morthisasterites</i> <i>tribrachiatatus</i>		
	<i>Globorotalia</i> (M) <i>aequa marginodentata</i>	EXT. G (M) <i>velascoensis</i> <i>velascoensis</i>	<i>Rhombaster</i> <i>cuspid</i>	G (M) <i>velascoensis</i> <i>velascoensis</i> , EXT.	
	<i>Globorotalia</i> (M) <i>velascoensis</i> <i>velascoensis</i>	IA. G (M) <i>aequa aequa</i>	<i>Discoaster</i> <i>mediosus</i>		G (M) <i>velascoensis</i> <i>velascoensis</i>
<i>Globigerina</i> (S) <i>triloculinoides</i>	GAP (?)		<i>Discoaster</i> <i>multiradiatus</i>		
	<i>Globorotalia</i> (P) <i>pseudamenardi</i>		GAP		G (P) <i>pseudamenardi</i>
			<i>Metolithus</i> <i>klempelti</i>	G (P) <i>pseudamenardi</i> , IA.	
	GAP (?)		<i>Fasciculitulus</i> <i>tympantiformis</i>		G. <i>pusilla pusilla</i> G (M) <i>angulata</i> G. <i>uncinata</i> G. <i>trinidadensis</i>
<i>Globigerina</i> (G) <i>pauciloculata</i>	<i>Globacantha daubjergensis</i>	EXT. G (G) <i>pauciloculata</i>	<i>Prinsius</i> <i>martinii</i>		G (T) <i>pseudobulloides</i>
	<i>Globigerina</i> (G) <i>pauciloculata</i>	IA. G. <i>daubjergensis</i>	<i>Chiasmolithus</i> <i>danicus</i>	G (T) <i>pseudobulloides</i> , IA.	
GAP (?)		IA. G (G) <i>pauciloculata</i>			G. <i>eugubina</i>

AFB



TEXT FIGURE 1

Sketch maps of postulated paleogeographic changes of Antarctica, Australia, and New Zealand from late Eocene to Recent based on reconstructions by Suggate (1972).

Due to the differences in the Paleogene planktonic foraminiferal fauna between southeastern Australia and the eastern coast of New Zealand it is postulated that there was in existence two distinct water masses. The

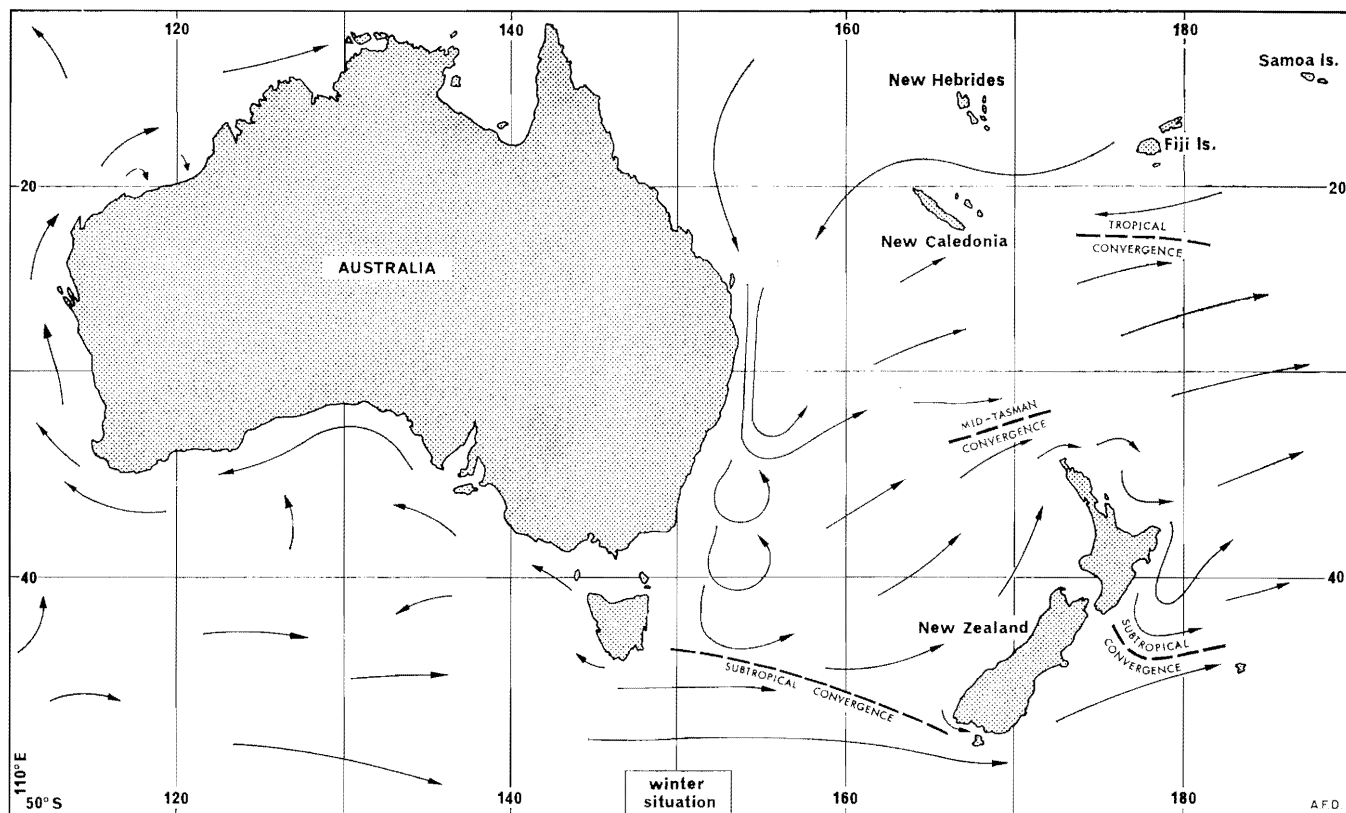
similarities in the faunas are due to a similar latitudinal belt position of the two areas. The southeastern Australian Paleogene water mass was fed by the west wind-drift current spreading in from the south Indian Ocean (text fig. 2). In New Zealand during the Paleocene-lower upper Eocene there was a different water regime, the east coast would have been covered by a south-westward-flowing current and if there had been a subtropical convergence as in the present day (see Kustanovich, 1963), it would probably have been positioned south of New Zealand. There was probably a change in the pattern of currents during the upper Eocene when cooler currents swept up along the east coast of New Zealand and similarly the west wind-drift would also have become cooler as the Antarctic region became cooler. This pattern of change became more pronounced when the circum-Antarctic current became established probably in the lower Oligocene. These postulated Paleogene paleocirculation patterns can be contrasted with the present-day oceanic currents (text fig. 2).

The dating of the initiation of the circum-Antarctic current appears to be fairly uncertain in the Oligocene having been previously postulated to have started in the late Oligocene (Kennett *et al.*, 1972) and middle Oligocene (Kennett *et al.*, 1973).

CORRELATION OF NEW ZEALAND AND AUSTRALIAN PALEOGENE

The main difficulties in correlating the lower Eocene-Oligocene planktonic foraminiferal faunas of the New Zealand and southeastern Australia are due to the non-existence of documented evolutionary lineages in the consequent reliance on extinctions and cryptogenic appearances for correlation, both of which are here considered to be diachronous events when used for long distance correlation (see Jenkins, 1965). Even so, it is hoped that some of the extinctions and cryptogenic appearances are events which can be utilised for reasonably accurate correlation. For example McGowran *et al.* (in Wopfner and Douglas, 1971) maintain that the extinction of *Pseudogloboquadrina primitiva* (Finlay) "gives an important horizon in Australasia" but there is very little evidence to support this hopeful statement.

The Paleogene planktonic foraminifera appear to be better represented in New Zealand rocks when compared with the published records from Western Australia, South Australia, and Victoria. In terms of geographic area the Paleogene has been recorded within latitudes 32°–46° S. Although both countries are within



TEXT FIGURE 2

Present day oceanic currents in the region of New Zealand, Australia, and Antarctica mainly from data supplied by M. J. Eade, New Zealand Oceanographic Institute and from Sverdrup and others (1946).

the same latitudinal Austral Belt there are marked differences in the planktonic foraminiferal faunas which are later discussed in more detail.

A zonal scheme for an upper Oligocene-upper Miocene sequence in Victoria (Jenkins, 1960) was later expanded to cover the whole Cenozoic in New Zealand (Jenkins, 1966; 1967). The zonal scheme has to a large extent been adopted but in parts slightly modified, and is widely used in Australia (table 3). This deliberate act on the part of some Australian micropaleontologists was a far better procedure than producing a rival zonal scheme within the Austral Belt. It therefore seems obvious that it will be possible to produce an acceptable Paleogene zonal scheme for the Austral Belt.

The Paleogene rocks of South Australia and Victoria lie between latitudes 37°–39° S which is equivalent in latitude position to the northern half of the North Island of New Zealand; therefore it is possible that the Australian faunas may correlate better with North Island sections. Examination was made of 17 stratigraphic

sections from the South Island (table 1) and five from the North Island of New Zealand.

There is good reason to believe that Carter (1958) has misidentified *Globigerina (Subbotina) linaperta* Finlay and it is in fact *G. (S.) angiporoides angiporoides* Hornibrook, at least in part (Jenkins, 1971). It should be noted that *G. (S.) linaperta* has distinctive compressed chambers as in the holotype (Finlay, 1939; Hornibrook, 1958; Jenkins, 1971). It will be important to establish if *G. (S.) linaperta* has been properly identified in southeastern Australia because there, it has a recorded range after the extinction of *Globigerinatheka (Globigerapsis) index index* (Finlay) which is different from New Zealand where both became extinct at the same level. Further, McGowran *et al.* (in Wopfner and Douglas, 1971) state that they "support previous authors in taking the disappearance of *Subbotina linaperta* as a good approximation of the Eocene/Oligocene boundary." It is not clear which previous authors are being referred to.

TABLE 3
New Zealand planktonic foraminiferal zones and subzones correlated with other areas in the Austral Belt.

EPOCHS	NEW ZEALAND PLANKTONIC FORAMINIFERAL ZONES AND SUBZONES		GIPPSLAND, VICTORIA (CARTER, 1959, 1964)	LAKES ENTRANCE OIL SHAFT, VICTORIA, AUSTRALIA (JENKINS, 1960)	VICTORIA (AFTER TAYLOR, 1966; in SINGLETON, 1968; in WOPFNER AND DOUGLAS, 1971)	PEBBLE POINT FORMATION AND UNDERNEATH THE RIVER NOOK MEMBER, WESTERN VICTORIA (AFTER MCGOWRAN, 1965)	PORT WILLUGA BEDS ALDINGA BAY (AFTER LINDSAY, 1967)
OLIGOCENE	G(G.) woodi connecta (part)		G dehiscens	G woodi	G woodi s.l., G kugleri, G dehiscens		
	G(G.) woodi woodi	G(G.) woodi woodi / G(T.) nana semivera G(T.) cf obesa		G dehiscens dehiscens			
	G dehiscens	G(G.) brazieri G dehiscens / G(G.) bradyi					
	G(G.) euapertura	G(G.) euapertura / G(G.) bullioides G(G.) labiacrassata G(G.) ciperensis angustilumbicata G(G.) ampliapertura	Victoriella conoidea	pre-G dehiscens dehiscens = Geuapertura zone in part	Geuapertura, G(T.) opima s.l. Ccubensis, G testarugosa	----- G slavensis	
	G(S.) angiparoides angiparoides	G(T.) gemma, G angiparoides, G brevis			Ccubensis		
	G(G.) brevis	G(G.) brevis / G(T.) gemma			G linaperta	G linaperta	
UPPER	G(S.) linaperta	G(G.) semiinvaluta G(T.) nana nana H alabamensis	G index	G ampliapertura / G linaperta G index H primitiva	T aculeata		
	G(T.) inconspicua	T collectea	-----				
	MIDDLE	EOCENE	G(G.) index index	G(G.) index index / G(T.) aculeata G(G.) index index / G(A.) soldadoensis		H. australis	-----
			P primitiva	G(S.) angiparoides minima G(T.) australiformis			
G(M.) crater crater		G(M.) crater crater / G(G.) boweri G(M.) dalabrata	----- ? ----- ? ----- ? -----				
G wilcoxensis		G wilcoxensis / G(M.) aequa rex	G cf. pseudamenardii - G chapmani ss.				
LOWER	PALEOCENE	G(S.) trilaculinoides	G(M.) aequa marginodentata G(M.) velascoensis velascoensis G(M.) aequa aequa G(P.) pseudamenardii	Taequa T affacuta G chapmani ehrenbergi	= G pseudamenardii = G pusilla - G angulata		
		(FAUNAL BREAK)	(FAUNAL BREAK)				
		G(G.) pauciloculata	G daubergensis G(G.) pauciloculata				
		(FAUNAL BREAK)					

McGowran *et al.* (in Wopfner and Douglas, 1971) have an enlarged *Globorotalia* (*Turborotalia*) *aculeata* Zone because this species appears to have become extinct much later in the upper Eocene of southeastern Australia as compared with its extinction level in New Zealand. This has resulted in the *Globigerina* (*S.*) *linaperta* Zone becoming compressed and represents a much smaller biostratigraphic interval (see table 3). Thus, from the published data on the extinction of *G. (T.) aculeata* in New Zealand, southeastern Australia, and France where it occurs in the Oligocene (D. Curry, private communication), it is important to emphasize that its extinction level is diachronous and therefore unreliable for accurate correlation.

Paleogene species common to both South Australia (after Ludbrook and Lindsay, 1969) and New Zealand have been plotted and ranges compared (table 4).

The following species, recorded in South Australia by Ludbrook and Lindsay (1969), have not been recorded in New Zealand: *Globigerina* (*Globigerina*) *davillensis* Howe, *G. (G.) officinalis* Subbotina, *G. (G.)*

praebuloides occlusa Blow and Banner, *G. (G.) pseudoeocenica* Subbotina, *G. (G.) senilis* Bandy, *G. (G.) yeguaensis* Weinzierl and Applin, *Globoquadrina dehiscens advena* Bermúdez, *G. larmei* Akers, *Hantkenina alabamensis compressa* Parr, *Guembelitrina* sp. cf. *G. columbiana* Howe, and *G. stavensis* Bandy. Similarly McGowran *et al.* (in Wopfner and Douglas, 1971) recorded the following: *Globigerina* (*Subbotina*) *frontosa* Subbotina *Cassigerinella winniana* (Howe) (their *C. eocenica*) and *Hantkenina primitiva* Cushman and Jarvis (= previously *H. alabamensis compressa* Parr).

The following species have been recorded in the New Zealand Paleogene but not as yet recorded in the lower middle Eocene-Oligocene rocks of equivalent age in southeastern Australia: *Candeina zeocenica* Hornibrook and Jenkins, *Globigerinita echinatus* (Bolli), *G. incrusta* Akers, *G. martini* Blow and Banner, *Globigerinathea* (*Globigerinathea*) *index barri* Brönnimann, *G. (Globigerapsis) semiinvoluta* (Keijzer), *Globigerina* (*Globigerina*) *brazieri* Jenkins, *Globigerinoides inusitatus* Jenkins, *Globorotalia* (*Acarinina*) *McKannai*

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TABLE 4

EPPOCHS	NEW ZEALAND PLAINTONIC FORAMINIFERAL ZONES	SOUTH AUSTRALIAN FORAMINIFERAL PLAINTONIC ZONES (FORSYTH, 1968)
OOLIGOCENE	G (G) woodi, conecchia (lower)	G woodi
	G (G) woodi, woodi	
	G debilem	G debilem
	G (S) eupheria	G eupheria
	G (S) angaparades angaparades	G angaparades angaparades
Eocene	G (G) brevis	G (G) brevis
	G (S) linaperia	G linaperia
	G (T) inconspicua	G (T) inconspicua
	G (G) index index	G index index
	G (T) primitiva	G primitiva G australiformis

recorded only three planktonic foraminifera, the new species *Globigerina patagonica* Todd and Kniker, together with *G. sp. cf. G. compressa* Plummer and *Globanomalina wilcoxensis* (Cushman and Ponton).

Gibson and Steineck (1972) recorded *Globigerina patagonica* from the Rose Canyon Shale, San Diego Basin, California, in rocks which they concluded to be of an early middle Eocene age. *Globigerina patagonica* was recorded with *Truncorotaloides collectea* (Finlay) and *T. spinoinflatus* (Bandy) in the Poway conglomerate; *Globorotalites suteri* Bolli and *Globigerina* cf. *G. ouachitaensis* Howe and Wallace are reported but are not present in the underlying Rose Canyon Shale. *Globigerina* (*Globigerina*) *patagonica* occurs with *Truncorotaloides spinoinflatus* and Bolli (1957c) records the latter from the middle Eocene *Hantkenina aragonensis* Zone to the *Porticulasphaera mexicana* Zone of Trinidad. Bolli (ibid.) recorded an overlap of ranges between *Truncorotaloides spinoinflatus* (Bandy) and *Globorotaloides suteri* Bolli in the *P. mexicana* Zone and therefore the occurrence of *Globigerina* (*Globigerina*) *patagonica* is probably within the range of *Hantkenina aragonensis*–*Globorotalia lehneri* Zones in the lower-middle Eocene.

Berggren (1969) recorded the association of *G. (G.) patagonica* and *Globanomalina wilcoxensis* (Cushman and Ponton) in the lower Eocene *Globorotalia formosa formosa* Zone to the lower *Globorotalia aragonensis* Zone of northern Europe. From an examination of the original figures of the holotype of *G. (G.) patagonica* its morphology seems to be very close to a taxon identified by Jenkins (1966; 1971, pl. 15, fig. 428–430) in New Zealand as *Globigerina (Globigerina) boweri* Bolli with a stratigraphic range of lower Eocene–lower middle Eocene *Globorotalia (Morozovella) crater crater* Zone to lower *Pseudoglobobadrina primitiva* Zone.

The following benthonic foraminifera were recorded by Todd and Kniker (1952) from the Agua Fresca Shale and have their equivalents in New Zealand. *Cibicides parkei* Finlay which has a range of middle Eocene to middle Oligocene *Pseudogloboquadrina primitiva* Zone–*Globigerina* (*Subbotina*) *angiporoides* Zone in New Zealand. *Elphidium lauritaense* Todd and Kniker is probably *E. saginatum* Finlay which is limited to the middle Eocene *Pseudogloboquadrina* primitive Zone–lowermost *Globigerinatheka* (*Globigerapsis*) *index index* Zone. *Gaudryina jacksonensis* Cushman is probably *G. proreussi* Finlay and is limited to the middle Eocene–upper Eocene *Globigerinatheka* (*Globigerapsis*) *index index* Zone to basal

Globorotalia (*Turborotalia*) *inconspicua* Zone. *Globanomalina wilcoxensis* (Cushman and Ponton) ranges in the lower Eocene *G. wilcoxensis* Zone to lower *Globorotalia* (*Morozovella*) *crater crater* Zone.

It is therefore concluded that the Agua Fresca Shale is probably equivalent to the lower Eocene-lower part of the middle Eocene, upper *Globorotalia* (*Morozovella*) *crater crater* Zone to lower *Globigerinatheka* (*Globigerapsis*) *index index* Zone. It is also noted that it contains a similar benthonic fauna to the equivalent rocks in New Zealand, across and on the eastern side of the Pacific. These observations support the statement by Hornibrook (1958) that the fauna from the Agua Fresca Shale "bears a striking resemblance to the New Zealand Heretaungan, Porangon and Bortonian."

CORRELATION WITH ARGENTINA

Malumian (1970) described a Danian fauna from the Pedro Luro Formation, Buenos Aires Province where he recorded *Globoconusa daubjergensis* (Brönnimann), *Subbotina triloculinoidea* Plummer, and *Turborotalia pseudobulloides* (Plummer). The fauna is correlated with the upper *Globigerina* (*Globigerina*) *pauciloculta* Zone of New Zealand.

Malumian *et al.* (1971) recorded a middle Eocene to lower upper Eocene fauna from the province of Santa Cruz. The fauna included *Globigerinatheka* (*Globigerapsis*) *index index*, *Truncorotaloides collactea*, and "*Subbotina* cf. *S. linaperta*" which appears to be *Globigerina* (*Subbotina*) *angiporoides minima* Jenkins. The fauna is correlated with the *Globigerinatheka* (*Globigerapsis*) *index index* Zone to *Globorotalia* (*Turborotalia*) *inconspicua* Zone of New Zealand (table 3).

Malumian and Masiuk (1973) have recently reviewed the records of foraminifera from Argentina including some Oligocene faunas from Cuenca Austral.

AUSTRAL PALEOGENE DEEP-SEA CORES

Margolis and Kennett (1971) recorded the following Paleogene planktonic foraminifera from four Subantarctic deep-sea cores:

Middle Eocene:

Core E24-9 from lat. 40° 35' S., long. 135° 08' W. yielded *Globigerinatheka* (*Globigerapsis*) *index*, *Globorotalia* (*Turborotalia*) *increbescens* Bandy, *Globorotaloides turgida* (Finlay), *Pseudoglobobulimina primitiva*, and *Truncorotaloides collactea*. Core E24-10 from lat. 37° 58' S., long. 134° 59' W. yielded *Globigerina* (*Globigerina*) *yeguensis*, *G.*

(*Subbotina*) *angiporoides*, *G. (S.) linaperta*, *Globigerinatheka* (*Globigerapsis*) *index*, *Globorotaloides turgida*, and *Pseudoglobobulimina primitiva*.

Lower Eocene:

Core E24-8 from lat. 42° 53' S., long. 134° 39' W. yielded *Globorotalia* (*Morozovella*) *aequa rex* Martin, *G. cf. convexa* Subbotina, *Globorotaloides turgida*, (Finlay) and *Pseudoglobobulimina primitiva*.

Core E13-4 from lat. 57° 46' S., long. 90° 48' W. yielded *Globigerina* (*Globigerina*) *patagonica*, *Globorotalia* (*Morozovella*) *aequa rex*, and *Pseudoglobobulimina primitiva*.

The faunas from these four deep-sea cores have been correlated with the New Zealand Paleogene planktonic foraminiferal zones (table 3). Margolis and Kennett (*ibid.*) also recorded two other Paleogene cores DWHG-34 and E23-19 which they assigned to the Oligocene but from the published data it has not been possible to verify their conclusions.

TASMAN SEA DEEP-SEA CORES

The Deep Sea Drilling Project Leg 21 drilled 3 holes in the North Tasman Sea at sites 206, 207, and 208 where the Paleogene was penetrated (Burns *et al.*, 1972). These faunas will be of special interest because they could form a link between the Austral and Tropical-subtropical Belts.

SOUTH ATLANTIC DEEP SEA CORES

According to Berggren and Amdur (1973), South Atlantic Oligocene planktonic foraminiferal assemblages exhibit a marked similarity with those of the Australasian region. Specifically they examined faunas from the three DSDP Leg 3 sites: (a) 14: (lat. 28° 19.89' S.; long. 20° 56.46' W.), (b) 17: (lat. 28° 02.74' S.; long. 6° 26.15' W.) and 18: (lat. 27° 58.72' S.; long. 8° 00.70' W.). From the published data the faunas would clearly fit into the concept of the Austral Belt. Consequently the suggested northern boundary for the Austral Belt at lat. 30° S. may have to be changed to a lower latitude position as more data becomes available.

CORRELATION WITH THE TROPICAL-SUBTROPICAL BELT

The correlation is based mainly on the stratigraphic records and zones erected by Bolli (1957a,b,c,) for

Trinidad and with zones which are now used in the Tropical-subtropical Belt. Although many of the species common in the low latitudes are not present in the Austral region, or are too rare to be of any value for accurate correlation, an attempt at a correlation has been made (table 2). The correlation is based on the following events in the two regions in descending stratigraphic order: *Globigerinatheka (Globigerapsis) semi-involuta* (extinction), *Globorotalia (Turborotalia) nana nana* (initial appearance), *Globigerinatheka (Globigerapsis) index index* (initial appearance), *Globorotalia (Morozovella) gracilis* (extinction), *G. (M.) velascoensis velascoensis* (extinction), *G. (Planorotalites) pseudomenardii* (initial appearance), and *G. (Turborotalia) pseudobulloides* (initial appearance).

EOCENE-OLIGOCENE BOUNDARY

Eocene-Oligocene Faunas: The planktonic foraminiferal fauna from the lower part of the upper Eocene is a widespread, relatively warm water fauna, with multi-apertured forms like *Globigerinatheka* which is a homeomorph of the late Oligocene-Recent warm water *Globigerinoides*. The fauna is radically different from the low-diversity fauna of the uppermost Eocene-lower middle Oligocene which consists mainly of *Globigerina* and *Globorotalia (Turborotalia)* and significantly lacks the Tropical-subtropical upper Eocene exotic forms such as *Hantkenina*, *Cribrohanthenina* and keeled *Globorotalia* such as *G. (Turborotalia) cerroazulensis*.

The recorded paleogeographic distribution of taxa in the upper Eocene-lower Oligocene tends to support the concept that there was a latitudinal belt pattern (Jenkins, 1965), but as the fauna became less diverse in the Oligocene it had a more uniform distribution as though worldwide conditions were more uniform.

There is a broad correlation between species diversity in the New Zealand upper Eocene-lower Oligocene and paleotemperature based on oxygen isotope analyses (Jenkins, 1968a, 1973). Tappan (1968) recorded a fall in the atmospheric oxygen in the Oligocene and this may coincide with the lowering of both temperature and diversity.

NEW ZEALAND

The Eocene-Oligocene boundary was placed between the Kaiatan and Whaingaroan Stages by Finlay (1947) where he recorded the last occurrence of *Discocyclus*, *Asterocyclus*, *Hantkenina*, and *Coleites* in the upper Eocene.

Later, the Eocene-Oligocene boundary was placed at the extinction of *Globigerinatheka (Globigerapsis) index index* at the interstage boundary between the Runangan and Whaingaroan (Hornibrook, 1958; Hornibrook in Fleming, 1959; Jenkins, 1963, 1966; Srinivasan, 1965). Hornibrook (*ibid.*) showed the extinction of *G. (G.) index index* coinciding with the extinctions of *Globanomalina micra* and *Hantkenina*. Later work (Jenkins, 1966, 1971), has shown that the extinction of *Globanomalina micra* (Cole) occurred slightly later, and *Hantkenina* became stratigraphically extinct much earlier than *Globigerinatheka (Globigerapsis) index index*. The placement of the boundary has been previously discussed by the writer (Jenkins, 1963) and later in more detail (Jenkins, 1970, 1971) where it was suggested that the boundary should be placed after the extinction of *G. (G.) index index* in the *Globigerina (Globigerina) brevis* zone. The reason for suggesting this later placement of the boundary was based on stratigraphic position of the boundary in other recorded sections (e.g., Trinidad) well after the extinction of *Globigerinatheka*.

AUSTRALIA

Carter (1958) illustrated a specimen which he identified as *Globigerina (Subbotina) linaperta* Finlay from the upper Eocene Brown's Creek, Victoria, Australia. Carter's figure appears to be of a specimen of *G. (S.) angiporoides angiporoides* Hornibrook. Specimens from the upper Eocene Glen Aire Clays, Victoria, identified by Dr. Carter as *G. linaperta* which have been deposited in the collections of the New Zealand Geological Survey, Lower Hutt, are definitely *G. (S.) angiporoides angiporoides*. Thus it is possible that *G. (S.) linaperta* recorded by Carter after the extinction of *Globigerinatheka (Globigerapsis) index index* is *G. (S.) angiporoides angiporoides*. If this is true then Carter's (1964) faunal unit 3 "*G. linaperta* zone" which was questioned Eocene of Oligocene, is equivalent to the upper part of the *Globigerina (Globigerina) brevis* Zone and the *G. (S.) angiporoides angiporoides* Zone of New Zealand.

With regards to the Eocene-Oligocene boundary, Carter (1964) concluded that "the top of the range of *Globigerinoides index* therefore seems the most useful indicator available for the top of the Eocene."

McGowran *et al.* (in Wopfner and Douglas, 1971) stated that they "support previous authors in taking the disappearance of *S. linaperta* as a good approximation of the Eocene-Oligocene boundary." But there is

TABLE 5

[illegible]

TABLE 6

[illegible]

a problem: In New Zealand *G. (S.) linaperta* became extinct at the same time as *Globigerinatheka (Globigerapsis) index index* whereas in South Australia (McGowran *et al.*) and Victoria (Carter, 1964), *G. (S.) linaperta* became extinct after *G. (G.) index*. It poses the question: Is the extinction of *G. (S.) linaperta* later in Australia as compared with New Zealand? If it is considered that *G. (G.) index index* became extinct in both countries at the same time, then *G. (S.) linaperta* has been recorded stratigraphically later than this event in southern Australia. Also a further question: Has *G. (S.) linaperta* been accurately identified in Australia? There is some evidence that it has been confused with *G. (S.) angiporoides angiporoides* as indicated in the previous discussion.

AUSTRAL AND TROPICAL-SUBTROPICAL BELTS

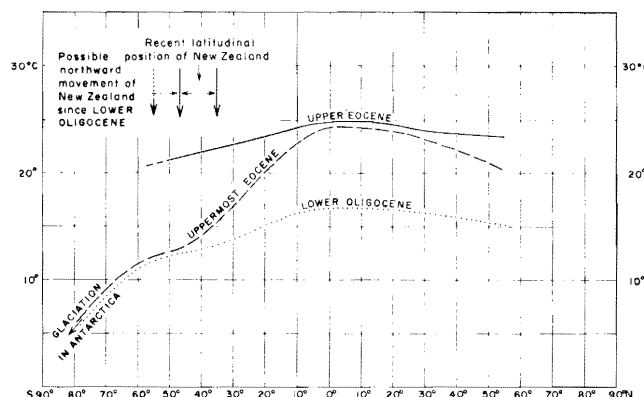
The ranges of the New Zealand planktonic foraminiferal and calcareous nannofossils (table 5) have been plotted across the Eocene-Oligocene boundary. By way of contrast the same two fossil groups and radiolaria recorded on Leg 9 DSDP (Hays *et al.*, 1972) from the Eastern Equatorial Pacific have been plotted (table 6).

From an examination of the two tables it can be seen that the biostratigraphic events are markedly different and consequently an accurate correlation between the two areas is very difficult.

DISCUSSION

There are biostratigraphic problems related to the Eocene-Oligocene boundary which may be directly related to a paleotemperature drop which has been recorded preceding the boundary in New Zealand. The cool temperature continued into the lower Oligocene and was first detected by oxygen isotope analysis by Devereux (1967; text fig. 3). The marine paleotemperature drop of 9° C has been considered to have affected the planktonic foraminiferal diversity and may have accounted for such extinctions as the *Globigerinatheka* species and other taxa in the lower *Globigerina (Globigerina) brevis* Zone (Jenkins, 1968a, 1968b, 1973).

There are problems resultant on the detection of the upper Eocene-Oligocene paleotemperature drop in New Zealand: (1) was the paleotemperature drop worldwide or was it more pronounced and located mainly in the Austral region, later spreading northwards? Unfortunately there are no comparable oxygen isotope

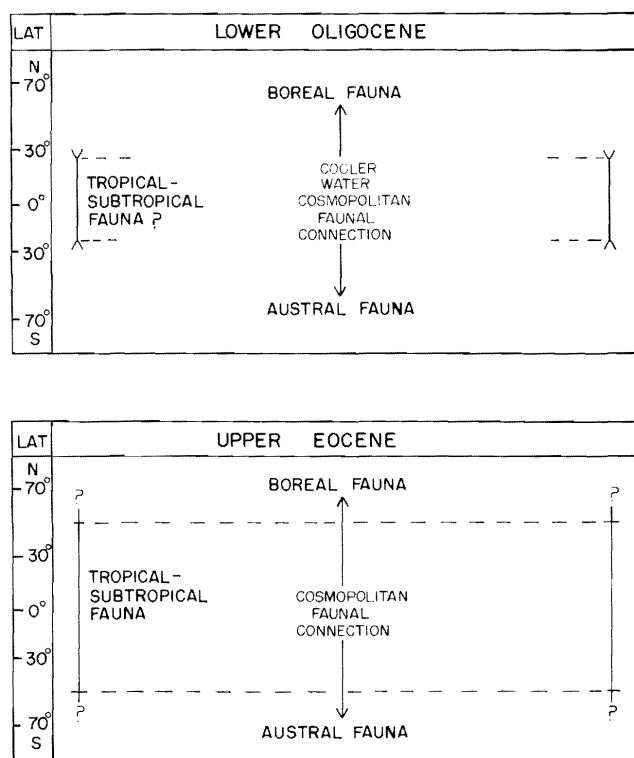


TEXT FIGURE 3

Postulated sequences of surface sea-water paleotemperature changes during the upper Eocene-lower Oligocene.

analyses across the boundary from other areas north of New Zealand; (2) if there was a worldwide temperature drop, is there any evidence of it having had a deleterious effect on marine plankton? Again this question is difficult to answer but there are a number of extinctions of planktonic foraminifera adjacent to or at the Eocene-Oligocene boundary in low-latitude sections as, for example, in Trinidad (Bolli, 1957b,c), Lindi area, Tanganyika (Banner and Blow in Eames *et al.*, 1962), and Barbados (Beckman, 1953). Close comparison shows that the extinctions were not simultaneous but were staggered over the boundary interval of uppermost Eocene-lowermost Oligocene. Thus the boundary is therefore far less dramatic than the extinction of most of the planktonic foraminifera which took place at the Mesozoic-Cenozoic boundary.

The Eocene-Oligocene boundary is more comparable to the Pliocene-Pleistocene boundary but appears to be more dramatic in New Zealand (Jenkins, 1971, Table 11). The drop in temperature in the Neogene appears to have started in the middle Miocene and thereafter certain warm-water taxa became locally extinct but survived in the warmer waters to the north. If there was a similar drop in temperature at the Eocene-Oligocene boundary then it is possible that certain species would have become locally extinct in the New Zealand region while surviving in the warmer waters to the north. If this premise is true, then it would support the concept of the diachronous nature of extinctions adjacent to the Eocene-Oligocene boundary. The paleotemperature drop at the Eocene-Oligocene boundary took place over a shorter time interval and this accounts for the more rapid succession of extinctions as com-



TEXT FIGURE 4

Changing distribution of planktonic foraminiferal faunas from upper Eocene to lower Oligocene with a postulated constriction of the tropical-subtropical belt.

pared with the Upper Neogene. There is evidence of glaciation in Antarctica in the Oligocene (Margolis and Kennett, 1971) but it appears to have been later in the Oligocene than the 9°C drop in sea-water temperature recorded by Devereux (1967). It is more than probable that this was a unipolar glaciation as compared with the bi-polar glaciation of the late Cenozoic.

Thus it can be postulated that the extinctions of planktonic foraminifera at or near the boundary were probably diachronous to varying degrees. A good example appears to be the extinction of *Globanomalina* (or of *Pseudohastigerina*) in the lower Oligocene (Blow, 1970; Jenkins, 1971). Not only were the extinctions diachronous but some of the cryptogenic appearances were also apparently diachronous. For example, *Cassigerinella winniana* Howe has been recorded in the Upper Eocene of low-latitude regions. In New Zealand *C. winniana* has not been recorded and *C. chipolensis* (Cushman and Ponton) did not appear until the middle-upper Oligocene *Globigerina* (*Globigerina euapertura* Zone whereas in southeastern Australia *C. win-*

niana (as *C. eocenica*) has been recorded in the upper Eocene and *C. chipolensis* appears in the lowermost Oligocene. A comparison of some of the species common to the 3 areas, New Zealand, Trinidad, and Lindi (Jenkins, 1971; tables 3, 4), tends to support the concept of there having been diachronous biostratigraphic events over the boundary.

To emphasize that the Tropical-subtropical upper Eocene-lower Oligocene fauna was different from the Austral fauna, the following is a list of species which have not as yet been recorded in the Austral Belt: *Chiloguembelina victoriana* Beckmann, *Cribohantkenina*, *Globigerina* (*Globigerina*) *gortanni* (Borsetti), *G. (G.) selli* (Borsetti), *G. (G.) venezuelana* Hedberg, *Globorotalia* (*Turborotalia*) *cerroazulensis* Cole, *G. (T.) permicra* Banner and Blow, *Globanomalina barbadoensis* Blow. Alternatively here are some species which have been so far recorded only in New Zealand and Australia: *Globigerina* (*Globigerina*) *brevis* Jenkins, *Candeina zeocenica* Hornibrook and Jenkins, *Globigerina* (*Subbotina*) *linaperta* (s.s.).

It is possible to make a direct comparison of the upper Eocene-Oligocene fauna from northwestern Europe (Berggren, 1969) and New Zealand to see if there is a similarity of faunas (table 7). The following are found in both belts but not as yet recorded from the Tropical-subtropical Belt: *Globigerina* (*Globigerina*) *labiacrassata* Jenkins, *G. (Subbotina)* *angiporoides* (but note that *G. cf. angiporoides* was recorded at site 77B, DSDP Leg 9 in the Eastern Equatorial Pacific, Hays *et al.*, 1972); *Globorotalia* (*Turborotalia*) *munda* (having a longer stratigraphic range in the Boreal Belt, see table 5); and *G. (T.) aculeata* in the middle-upper Eocene in New Zealand and Australia but recorded from the upper Eocene-Oligocene of France.

TIME-SEQUENTIAL PALEOBIOGEOGRAPHY

There is evidence that the upper Eocene planktonic foraminiferal fauna was broadly differentiated with some taxa restricted to the Tropical-subtropical Belt but with the majority having a cosmopolitan distribution (text fig. 4). At this stage in time, the Boreal Belt appears to have had warmer water taxa as compared with the Austral Belt. The uppermost Eocene cooling which probably started in Antarctica and spread northwards first affecting the Austral fauna, resulted in the extinction of a number of species including *Globigerinatheka* (*Globigerapsis*) *index*, *G. (G.) index barri*, *G. (G.) semiinvoluta*, *Globigerina* (*Subbotina*) *linaperta*, and slightly later *Globanomalina micra* became extinct in

TABLE 7

0.5

It is postulated that even though the Austral cooling was probably initiated by a uni-polar glaciation in Antarctica, the next area to become cool was the already potentially cooler Boreal Belt. This would have occurred in the lowermost Oligocene and was followed by the subsequent cooling of all the oceans with a greatly restricted Tropical-subtropical Belt (text fig. 4).

The dominance of what appear to be cooler water forms of *Globigerina* and *Globorotalia* (*Turborotalia*) in the Lower Oligocene fauna coupled with the low-species diversity tends to confirm the lowering of sea-water temperature in the uppermost Eocene-lower Oligocene.

CONCLUSIONS

1. For the most of the Paleocene and Eocene, but excluding the uppermost Eocene, there was a cosmopolitan planktonic foraminiferal fauna but with some more specialised taxa restricted to the Tropical-subtropical Belt. The lowermost Danian *Globigerina eugubina* Zone fauna has not as yet been identified from the Austral Belt.

CONCLUSIONS

2. The paleotemperature cooling in the upper Eocene and which extended into the lower Oligocene probably started in Antarctica and spread northwards to the Austral Belt, next affecting the already relatively cooler Boreal Belt and finally affecting the Tropical-subtropical Belt. This cooling, recorded as a drop of 9°C in New Zealand, affected the planktonic foraminifera by rapidly lowering the species diversity. The extinctions adjacent to the Eocene-Oligocene boundary appear to be diachronous but with the relatively primitive methodology of comparing successive biostratigraphic events it is not possible to prove the amount of diachrony. Nevertheless it must be emphasised that there is some doubt whether the consistent placement of an Eocene-Oligocene boundary, based on extinctions and cryptogenic appearances of planktonic foraminifera as an accurate time boundary can be achieved. Consequently it is suggested that one well-documented and well-marked biostratigraphic event in the European type section be chosen and thereafter it should be permanently fixed for correlation.

3. Examination of the New Zealand and south-eastern Australian fauna shows the expected resemblances but because of the significant differences it is postulated that the faunas represent two distinct water masses.

4. Glaciations reported in Paleocene deep-sea cores north of Antarctica in the South Pacific are reflected to varying degrees in the New Zealand fauna. *Pseudoglobobulina primitiva* could have become adapted to the cooler water conditions of the lower middle Eocene in the higher latitudes (Jenkins, 1973).

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