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Australasian mid-Tertiary larger foraminiferal associations and their bearing on the East Indian Letter Classification

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Eight larger foraminiferal associations are found in northwest Australia; some can be recognised in other areas of Australia, New Zealand, Papua New Guinea, and Irian Jaya. Correlation with the East Indian Letter Classification can be made for some associations, but there is difficulty with others, owing to the absence of diagnostic forms. Planktic faunas are present in some of the associations, enabling direct correlation with the tropical planktic zonal scheme. In those non-diagnostic associations containing *Cycloclypeus* or *Lepidocyclina (Nephrolepidina)*, correlation with the East Indian Letter Classification can be achieved using biometric methods. The Tertiary *e* stage–Tertiary *f* stage boundary is placed within the N.6-7 zonal interval.

Introduction

Eight associations of larger foraminiferids have been recognised in the North West Cape area (Figs. 1, 2). Most can be recognised in Ashmore Reef No. 1 well (Figs. 1, 3) and some in the Batesford Limestone (Figs. 1, 4) (Chaproniere, 1975). Their recognition also in Irian Jaya and Papua New Guinea demonstrates their validity as biologic entities. The associations have a limited stratigraphic range in all sections (Figs. 2, 3, 4), and there are at least two successive associations in each section. Those from North West Cape and Ashmore Reef No. 1 well are in a similar order (Figs. 2, 3); those from the Batesford Limestone show a similar relationship, but are in a different order (Fig. 4).

Because it has been argued that the distribution of these assemblages is facies controlled (Chaproniere, 1975), their usefulness for biostratigraphic correlation may be limited. However, accurate time-correlation can be achieved in some associations by detailed biometric studies (Chaproniere, 1980), even between areas as widely separated as Batesford (Victoria) and North West Cape (Western Australia), suggesting that gene flow was maintained within the Australian region. For biostratigraphic convenience, the associations have been abbreviated to numbers prefixed by the letters LF (= larger foraminiferids), and are summarised in Table 1. Table 1 also gives their correlation with both the planktic foraminiferal scheme of Blow (1969), as modified for local usage by Chaproniere (1981), and the letter stage classification of Adams (1970).

Even though it is unusual for larger foraminiferal faunas to be associated with good planktic foraminiferal assemblages, several such associations occur in both Australia and New Zealand, and have formed the basis for this paper and for Chaproniere (1980). Such faunal relationships have permitted a better understanding of the correlation between the planktic and letter classification schemes, at least within the Australasian region. Furthermore, for the first time, the Tertiary *e*–Tertiary *f* stage boundary can be correlated with the tropical planktic foraminiferal zonal scheme.

Stratigraphic details

Detailed descriptions of the sections which are the basis for this paper are given in Chaproniere (1975, 1976), and all necessary lithostratigraphic and biostratigraphic details are summarised in Figures 2, 3, and 4. Figure 5 gives the stratigraphic ranges of the larger foraminiferids used in Table 1, for northwestern Australia.

Correlation with the East Indian Letter Classification

Adams (1970), in a discussion of the East Indian Letter Classification, listed typical assemblages for each letter stage, and noted problems with the definition of the stage boundaries. In the North West Cape area, the majority of the faunas contain only a few of the taxa regarded as typical of the Tertiary lower *e* to lower *f* stages. It is difficult, therefore, to locate exactly

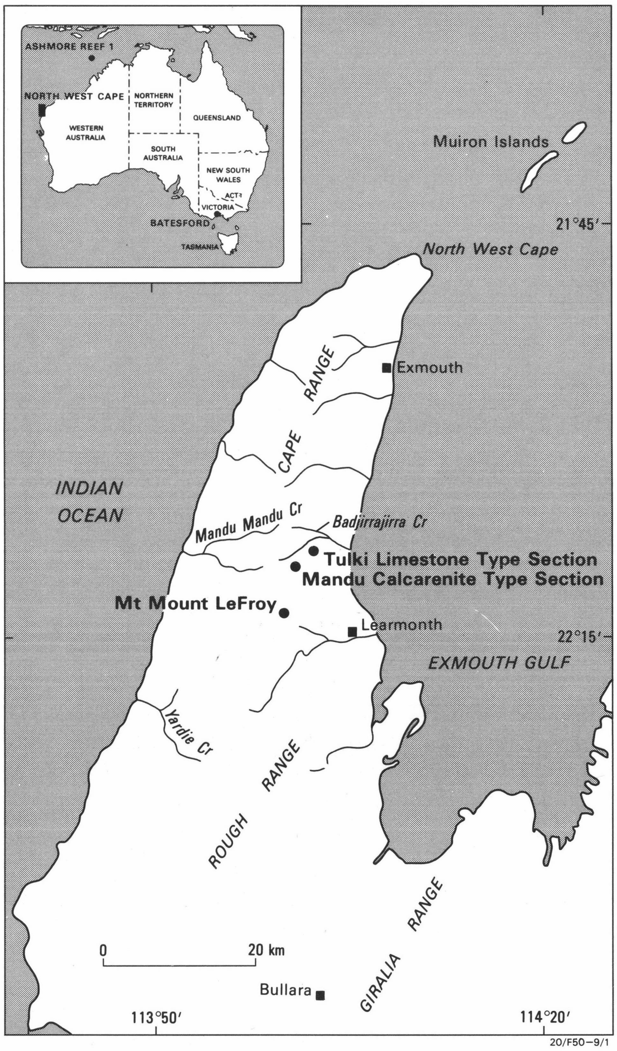

Figure 1. Locality map.

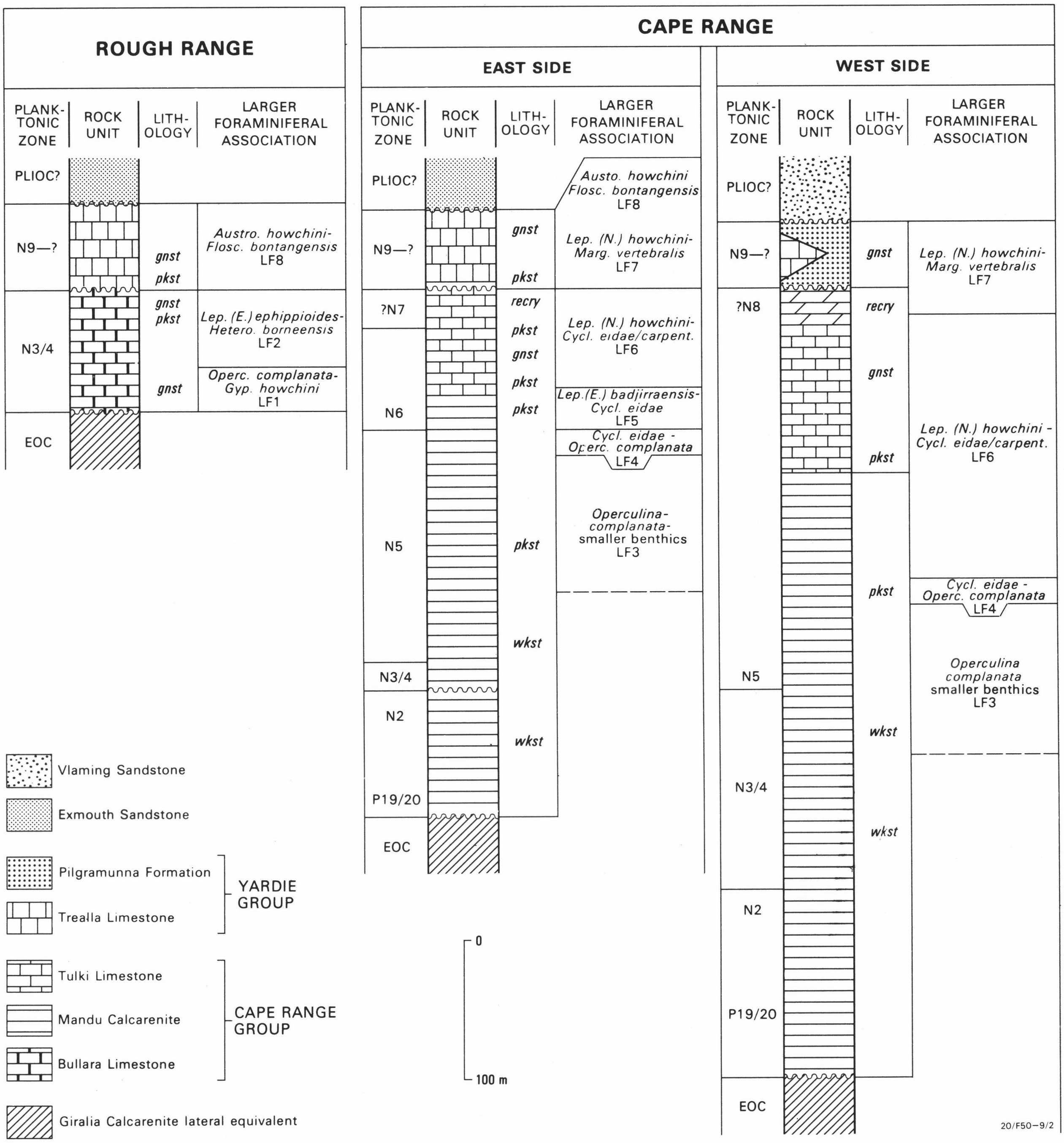

Figure 2. Composite stratigraphic sections from three localities in the North West Cape area, showing the relationship between the planktic and larger foraminiferal biostratigraphic schemes (modified after Chapronière, 1975).

the position in the Letter Classification of most of the associations.

Furthermore, the difficulties are increased by different workers not having uniform concepts of some of the key species. Many of the specific names for *Lepidocyclina (Nephrolepidina)* used by Adams (1970) have been applied to a great variety of morphotypes by many different authors using differing criteria (see those figured by Ellis & Messina, 1965). Adams (1965) indicated his intention to describe fully, in a later paper, the species on which his study was based. At present it is almost impossible to have a clear picture of any of these species, and they are difficult to equate to those of the present study, which uses taxa based on biometric criteria (Chapronière, 1980). In addition, of the numerous species of *Cycloclypeus* described by Tan (1932) for this same interval of time, only two are used here, and these are based on the usage of MacGillavry (1962) (see Chapronière, 1980); critical species such as *C. eidae* Tan, *C. posteidae* Tan, and *C. indopacificus* Tan (as used by Adams, 1970) are difficult to recognise using Tan's (1932) criteria (see MacGillavry, 1962; Drooger, 1955), and almost certainly Adams (1965, 1970) has a concept of those species different from that of other workers and that used by the present writer.

All these factors have made very difficult any attempt to refer the associations described above to the Letter Classification. However, it is fairly certain that the LF.2 association is Tertiary lower *e* (based on the presence of *Heterostegina borneensis* van der Vlerk, *Lepidocyclina (Eulepidina) ephippioides* Jones & Chapman, *L. (Nephrolepidina) sumatrensis* (Brady)—*parva* Oppenoorth morphotype, and *Austrotrillina striata* Todd & Post), that LF.5 is Tertiary upper *e* (based on the presence of *L. (E.) badjirraensis* Crespin with *Cycloclypeus eidae* Tan—*sensu* MacGillavry, 1962, *Miogypsina (Miogypsinoides) dehaarti* van der Vlerk and the *L. (N.) howchini* Chapman & Crespin group—*sumatrensis* (Brady) morphotype), and that LF.8 is Tertiary lower *f* (based on the presence of *Flosculinella bontangensis* (Rutten) with *Austrotrillina howchini* (Schlumberger)).

The other associations are difficult to place within this time range. The lowest assemblages from New Zealand contain elements that are typical of both Tertiary lower and upper *e* stages. *L. (Nephrolepidina) orakeiensis orakeiensis* (Karrer) is similar to *L. (N.) sumatrensis* (*parva* type), but is slightly more advanced; this form occurs with *Heterostegina borneensis* and either *Miogypsina (M.) globulina* (Michelotti) or *M. (M.) intermedia* Drooger. *H. borneensis* is typical of the Tertiary lower *e* stage and has only been questionably recorded from the Tertiary upper *e* stage (Adams, 1970). *Miogypsina (Miogypsina)*, on the other hand, first appears in the Tertiary upper *e* stage, and

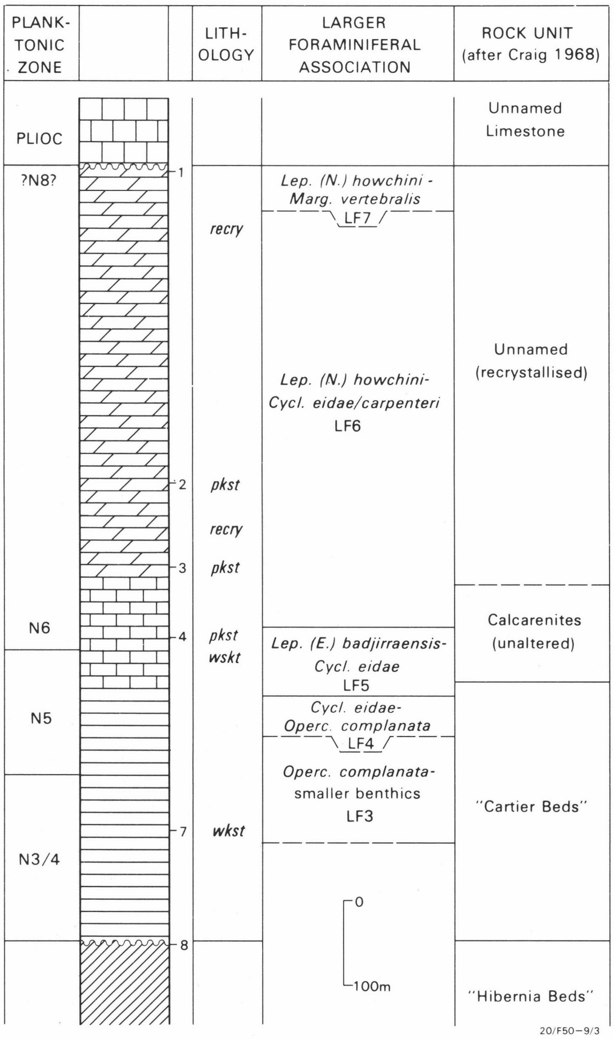

Figure 3. Stratigraphic summary of the Oligo-Miocene section in Ashmore Reef No. 1 Well (modified after Chaproniere, 1975, 1981).

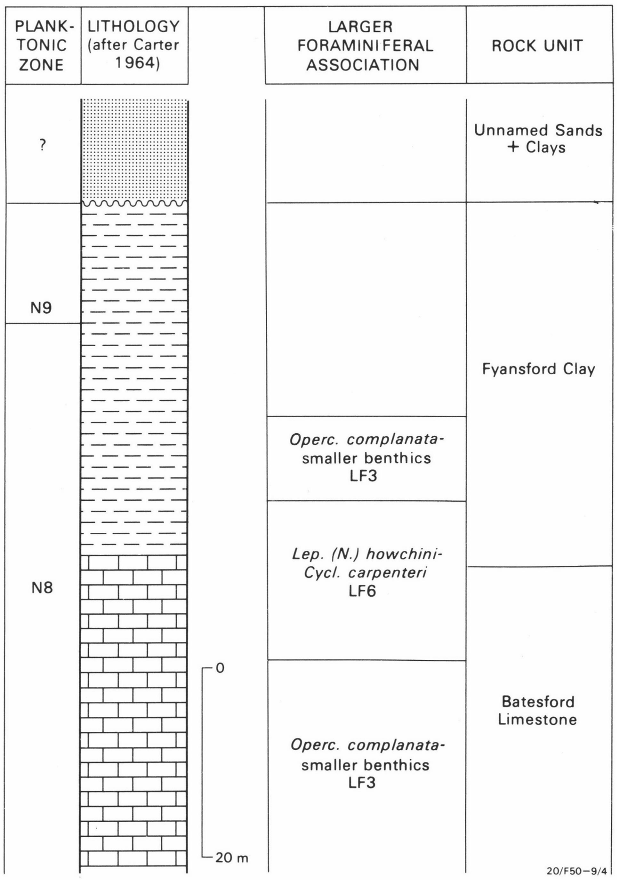

Figure 4. Stratigraphic summary of the Batesford Limestone, Batesford, Victoria (modified from Carter, 1964, fig. 15, and after Chaproniere, 1975).

has not been recorded from assemblages that would otherwise be clearly referable to the Tertiary lower *e* stage (Adams, 1970). The overlap between *H. borneensis* and *Miogypsina (Miogypsina)* occurs in two assemblages containing planktic foraminiferids; one containing *M. (M.) globulina,* contains a Zone N.3/4 fauna, and the other, with *M. (M.) intermedia,* contains a Zone N.5 fauna. Clarke & Blow (1969) place the Tertiary lower *e*–upper *e* stage boundary at the base of Zone N.4 of Blow (1969), while Adams (1970) places it within Zone N.4 (Fig. 6); both these assignments probably correlate to within the upper parts of Zone N.3/4 of Chaproniere (in Shafik & Chaproniere, 1978).

Thus, it would seem that the planktic and larger foraminiferal data suggest that the New Zealand faunas are from the Tertiary lower–upper *e* stage boundary, and that the boundary itself covers the planktic interval from high in Zone N.3/4 to low in Zone N.5. Biometric methods as outlined by Chaproniere (1980) would seem to be the best way to resolve the position of those non-diagnostic faunas, which contain species amenable to such treatment, within the Letter Classification scheme. However, some contain very long ranging forms and cannot, at present, be precisely placed.

The LF.1 and LF.3 associations are based on a long-ranging species, *Operculina complanata* (Defrance); LF.1 also contains *Lacazinella* sp. cf. *L. wichmanni* (Schlumberger). This form, as noted by Chaproniere (1976), is almost certainly reworked from Eocene sediments. In northwestern Australia the LF.1 association conformably underlies the typically

	LARGER FORAMINIFERAL ASSOCIATION	ASSOCIATED LARGER FORAMINIFERIDS	PLANKTONIC ZONE AUSTRALIA NW	PLANKTONIC ZONE AUSTRALIA E	PLANKTONIC ZONE NEW ZEALAND	E.I. LETTER STAGE	AGE
LF8	*Austrotrillina howchini - Flosculinella bontangensis*	*Marginopora vertebralis, Sorites* sp., *Peneroplis* sp., *Borelis pygmaeus, Operculina complanata, O. venosa, Cycloclypeus (Cycloclypeus)* sp. cf. *C. carpenteri, Gypsina globulus, G. howchini, G. mastaelensis,* and *Lepidocyclina (Nephrolepidina)* sp. cf. *L. howchini*	N9-?N12			lower T*f*	Middle Miocene
LF7	*Lepidocyclina (Nephrolepidina) howchini - Marginopora vertebralis*	*Austrotrillina howchini, Borelis pygmaeus, Operculina complanata, O. venosa, Cycloclypeus (Cycloclypeus)* sp. cf. *C. carpenteri, Miogypsina (Lepidosemicyclina)* sp. cf. *M. thecideaeformis, Amphistegina quoyi, Borodinia septentrionalis, Gypsina globulus, G. howchini, G. mastaelensis; Cycloclypeus (Katacycloclypeus)* sp. cf. *C. annulatus* is very rare.	N9-?N12			lower T*f*	Middle Miocene
LF6	*Lepidocyclina (Nephrolepidina) howchini - Cycloclypeus (Cycloclypeus) eidae / carpenteri*	*Operculina complanata, Miogypsina (Lepidosemicyclina) thecideaeformis, Amphistegina quoyi, Gypsina globulus, G. howchini, Heterostegina suborbicularis, Miogypsina (Miogypsinoides) dehaarti, Borodinia septentrionalis, Carpenteria alternata,* and *C. proteiformis*	N6-N8	N8	N10-12	lower T*f*	Early Miocene
LF5	*Lepidocyclina (Eulepidina) badjirraensis - Cycloclypeus (Cycloclypeus) eidae*	*Operculina complanata, Amphistegina quoyi, Gypsina globulus, Carpenteria alternata,* and *Lepidocyclina (Nephrolepidina) howchini*	N5-N6			upper T*e*	Early Miocene
LF4	*Cycloclypeus (Cycloclypeus) eidae - Operculina complanata*	*Gypsina globulus, Carpenteria alternata,* and juvenile *Lepidocyclina (Eulepidina) badjirraensis*	N5-N6			upper T*e*	Early Miocene
LF3	*Operculina complanata* - smaller benthic foraminiferid	Juvenile *Cycloclypeus (Cycloclypeus) eidae* and juvenile *Lepidocyclina (Eulepidina) badjirraensis*	N5	N8		T*e* to T*f*	Early Miocene
LF2	*Lepidocyclina (Eulepidina) ephippioides - Heterostegina Borneensis*	*L. (Nephrolepidina) sumatrensis* and *Amphistegina bikiniensis, Operculina complanata, Gypsina globulus, G. howchini, Austrotrillina striata, Sorites* sp., *Borelis pygmaeus,* and *Halkyardia* sp. cf. *H. minima. Miogypsina (M.)* spp., and *L. (N.) orakeiensis* in N.Z.	N3/4		N3/4-N5	lower T*e*	Late Oligocene
LF1	*Operculina complanata - Gypsina howchini*	Rare specimens of *Lacazinella* sp. cf. *L. wichmanni*, probably reworked from the underlying lateral equivalents of the Giralia Calcarenite, are also present	N3/4			T*e*	Late Oligocene

20/F50—9/8

Table 1. Summary of the larger foraminiferal associations from the Australian area (from Chapronieré, 1975) and their relation to the planktic zonal scheme and the East Indian Letter Classification.

Tertiary lower *e* stage LF.2, and almost certainly correlates with that Letter Stage. LF.3 underlies typical Tertiary upper *e* stage faunas, and so is best equated with that stage. At Batesford, however, the LF.3 association contains a Zone N.8 planktic fauna, and, as noted below, this is equivalent to the Tertiary lower *f* stage.

The LF.4 and LF.6 associations contain either *Cycloclypeus* or *Lepidocyclina (Nephrolepidina)*, and so, by using biometric criteria, should be readily correlated with the Letter Stage Classification. As noted above, however, problems of nomenclature impede such correlation. Table 2 lists the species of *Clycloclypeus (Cycloclypeus)* and *L. (Nephrolepidina)* given by Adams (1970) for the Letter Stages Tertiary lower *e* to upper *f*. If biometric criteria were to be used, values for parameters such as pc (the number of chambers in the precyclic stage—see O'Herne & van der Vlerk, 1971; Chapronière, 1980) would decrease, while Spc_{4+5} (the number of secondary chamberlets of the 4th and 5th precyclic chambers) would increase, for populations of *Cycloclypeus (Cycloclypeus)* from Tertiary lower *e* to Tertiary upper *f* stages.

In a similar way, parameter F (which is a measure of the arrangement of the equatorial chambers—see Chapronière, 1980) for *L. (Nephrolepidina)* would be seen to increase in value. Within the Australian region, populations from Tertiary lower *e* are dominated by specimens with an intersecting curve arrangement of the equatorial chambers: those from Tertiary upper *e* have a circular to polygonal concentric arrangement, those from Tertiary lower *f*, a stellate arrangement, and those from upper *f*, a similar arrangement as in lower *f*, but with many specimens having a complicated multilepidine embryoconch. At all levels, both phylogenetically primitive and advanced specimens could be expected to be found, but the proportions would gradually change—thus in Adams' (1970) lists, advanced forms (stellate), such as *ferreroi* Provale and *martini* (Schlumberger), occur with primitive types (circular concentric), such as *sumatrensis*, in, for example, Tertiary lower *f* stage (Table 2).

From this information, the LF.4 and LF.6 associations are seen to be time transgressive. Those from the eastern side of Cape Range contain phylogenetically more primitive forms than those from the western side.

Letter stage	*Cycloclypeus (Cycloclypeus)*	*Lepidocyclina (Nephrolepidina)*
Upper T*f*	*carpenteri/guembelianus*	*rutteni, radiata, orientalis, talahabensis*
Lower T*f*	*posteidae, indopacificus*	*ferreroi, sumatrensis, martini, japonica, orientalis*
Upper T*e*	*eidae* group	*inflata, japonica, sumatrensis, verbeeki*
Lower T*e*	*eidae*	*isolepidinoides, parva*

Table 2. Species of *Cycloclypeus (Cycloclypeus)* **and** *Lepidocyclina (Nephrolepidina)* **considered by Adams (1970) to be typical of the late Oligocene and Miocene Letter Stages.**
Adams & Frame (1979) have recently demonstrated that *C. carpenteri* and *C. guembelianus* are synonymous.

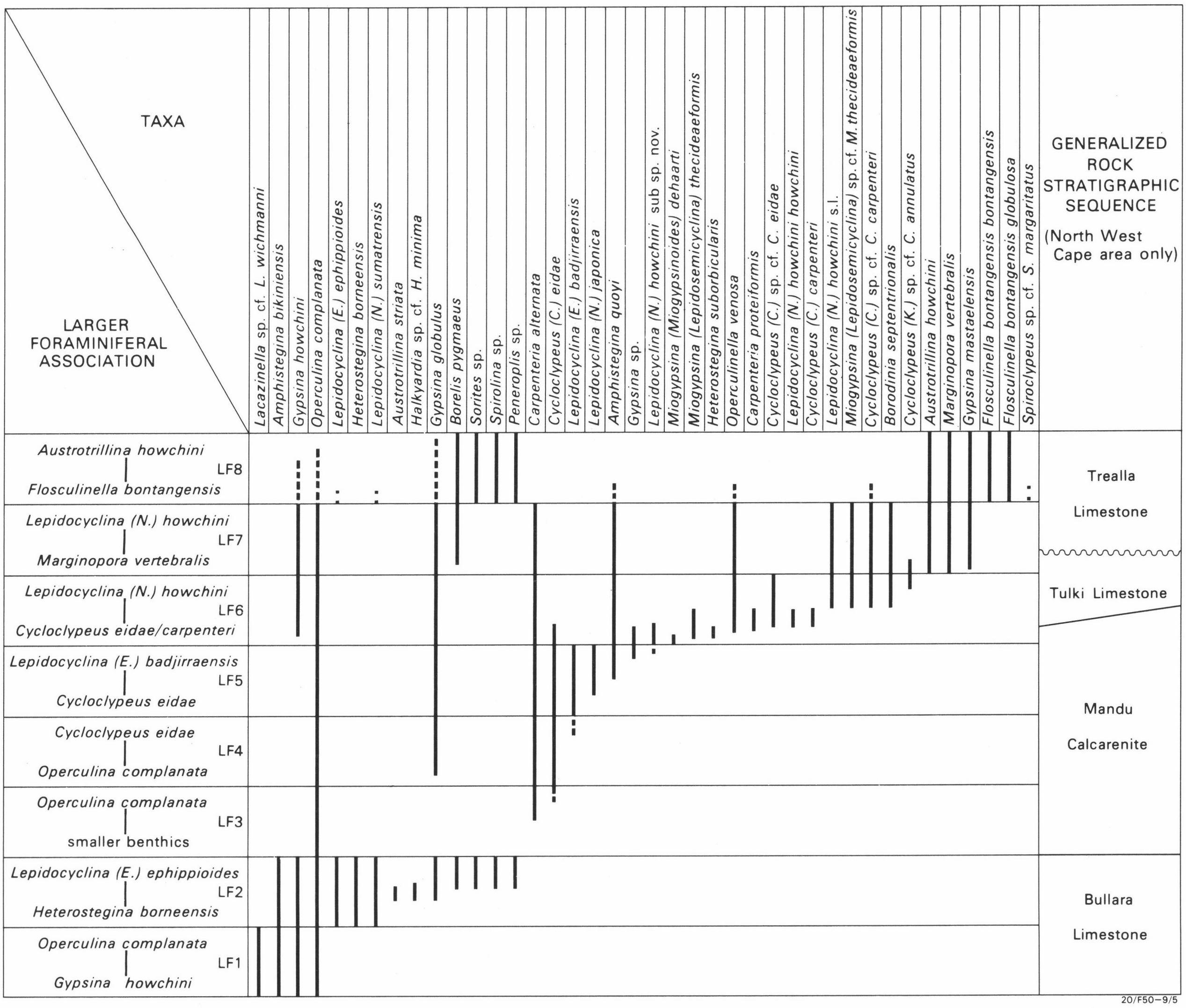

Figure 5. Generalised biostratigraphic range chart of larger foraminiferids in late Oligocene-early Miocene rocks of northwest Australia.
Dashed lines indicate ranges of juvenile or small adult forms; dotted lines indicate reworked specimens.

In addition, both associations occur close to typical Tertiary upper *e* stage faunas on the eastern side, suggesting that there they are best correlated with that stage. In contrast, as will be argued below, those associations from the western side are from levels above the extinction of *Lepidocyclina (Eulepidina) badjirraensis,* and so are best referred to the Tertiary lower *f* stage. The LF.7 association conformably overlies the LF.6, and underlies the LF.8 associations, and is best considered Tertiary lower *f* stage in this region.

The Tertiary *e*–Tertiary *f* stage boundary

The boundary between the Tertiary upper *e* and Tertiary lower *f* stages is difficult to locate, as it is based mainly on the extinction level of both *Spiroclypeus* (which occurs only as reworked specimens higher in the succession within the study area) and *L. (Eulepidina)* (Adams, 1965, 1970).

There is good evidence that *L. (E.) badjirraensis* became extinct within the early parts of the zonal interval N.6-7 in northwest Australia. In the North West Cape area and in Ashmore Reef No. 1 well the highest assemblages of *L. (E.) badjirraensis* are phylogenetically very advanced, as based on biometric criteria (Chaproniere, 1980), and are at a similar development to those of *L. (E.) dilatata* (Michelotti) described by Lange (1968) from Greece; in both areas, the majority of specimens have the protoconch almost completely enveloped by the deuteroconch, a stage above which no other is known, and it is difficult to visualise any evolutionary advancement beyond it.

One of the most persistent and widespread evolutionary trends throughout the larger foraminiferids is the gradual reduction with time of the coiled stage prior to the development of radial growth, and in the lepidocyclines it is taken to its ultimate by the almost total envelopment of the protoconch by the deuteroconch; in *Nephrolepidina,* peculiar multilepidine embryoconchs dominate assemblages prior to the extinction of that group. Thus, in the writer's opinion, it is safe to conclude that soon after the highest known stratigraphic occurrence of *L. (Eulepidina) badjirraensis* in Badjirrajirra Creek on the eastern side of Cape Range, and at a level just above core 3 in Ashmore Reef No. 1 well, this subgenus became extinct.

Further evidence to support this conclusion lies in the presence of identical smaller benthic foraminiferal faunas at levels within the Mandu Calcarenite, both on the eastern and western sides of Cape Range (*L. (E.)*

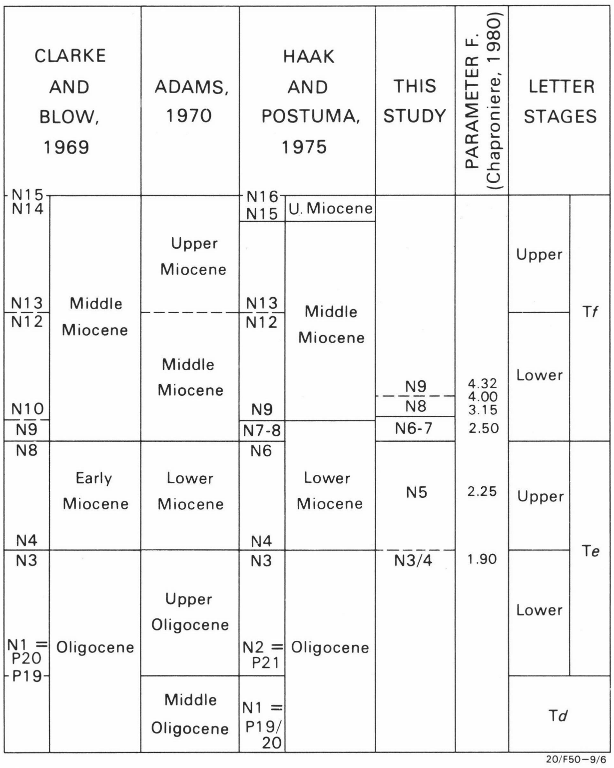

Figure 6. Comparison of relations between the Letter Stages and planktic foraminiferal zonal scheme given by other workers and as used in this paper. Some values for parameter F for *Lepidocyclina (Nephrolepidina)* are also given.

badjirraensis has not been recorded from the latter, which is also younger), suggesting that environmental conditions would not cause the exclusion of this subgenus.

Thus, in the northwest Australian region, the boundary between the Tertiary upper *e* and lower *f* stages can be defined on the extinction level of *L. (E.) badjirraensis* (top of LF.5), an event which occurred within the early part of the zonal interval N.6-7, which is somewhat earlier than that recorded by Adams (1970), Clarke & Blow (1969) and Haak & Postuma (1975).

Although support for the location of the Tertiary *e*—Tertiary *f* stage boundary within the N.6-7 zonal interval for the Australian region can be considered as tenuous, faunas from Irian Jaya and Papua New Guinea give some support to the case argued above. A sample from the basal part of the Moon Volcanics (Pieters & others, in prep.) on the Wesauni River in Irian Jaya contains a good lower Tertiary *f* assemblage (*Flosculinella bontangensis* with *Cycloclypeus* sp. and *Lepidocyclina (N.)* sp. cf. *L. (N.) howchini*) and is overlain by a mudstone with a typical Zone N.8 fauna, containing planktic forms best referred to *Praeorbulina glomerosa* rather than *Orbulina suturalis*. At several localities in the Blucher Range 1:250 000 Sheet area of Papua New Guinea, good Zone N.8 planktic faunas (*Praeorbulina* without *Orbulina*) overlie assemblages typical of the LF.6 association.

These results are in conflict with the statements of Clarke & Blow (1969) and Eames & others (1962) who recorded *L. (Eulepidina)* and other typically Tertiary *e* stage forms with either *Praeorbulina* or *Orbulina suturalis* (Zone N.8 or N.9) in 'Kereruan' stage limestones from Papua. This association was not adequately documented by these workers, and even though the figures given by Eames & others (1962, Pl. V) clearly show *L. (Eulepidina)* and other typical Tertiary *e* stage taxa, no planktic forms can be seen. In addition, unpublished reports of the Australian Petroleum Company indicate that the larger foraminiferids are allochthonous.

Clearly this association needs restudy, but in the light of evidence presented above, the writer believes the record of *L. (Eulepidina)* in Zone N.8 or N.9 doubtful and unlikely. Although accurate assessment of the values for parameter F cannot be made from random thin sections, some indication of the values for this parameter can be achieved (see Appendix 1); evidence suggests that the mean values of parameter F are similar to those of populations from the western side of Cape Range and, thus, of levels above the extinction level of *L. (Eulepidina)*. Moreover, this subgenus is not associated with these faunas. In at least one section (from the headwaters of the Sepik River, Victor Emanual Range) an LF.6 assemblage occurs with a typical Zone N.8 fauna, and is indistinguishable from a similar fauna occurring in the Batesford Limestone of Victoria.

Conclusions

There is no doubt that the Tertiary *e*—Tertiary *f* boundary correlates with levels below the Zone N.8-N.9 boundary (the early-middle Miocene boundary), the position which Clarke & Blow (1969) and Adams (1970) preferred (on evidence available at that time), because of the presence of good Tertiary lower *f* stage faunas with typical Zone N.8 planktic faunas. There is good evidence that this boundary occurs at least within Zone N.8 (see also Haak & Postuma, 1975), and that it even occurs within the zonal interval N.6-7 in the Australian area. The problem of the Tertiary *e*—Tertiary f boundary is made the more difficult in that it is characterised by the extinction level of two taxa *(Spiroclypeus)* and *Lepidocyclina (Eulepidina)*, both of which seem to be excluded from the LF.6 association (an association very widely distributed in the region) on probable environmental grounds (see Chapronière, 1975).

Acknowledgements

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Appendix 1. The estimation of parameter F for *Lepidocyclina* (*Nephrolepidina*) in random thin-sections.

Chaproniere (1980) proposed parameter F for *L. (Nephrolepidina),* and indicated that, of all the parameters used in biometric studies of the taxon, this proved to be the most accurate for correlation. That study was based on oriented thin-sections of individual specimens, as accurate measurements could not be made from random thin-sections. Subsequent work has shown that if sufficient random thin-sections are examined, an estimation of the value of parameter F can be obtained. This is due to the form of the equatorial layer in vertical sections which are not centred, that is, in sections which cut the test tangentially, at a distance from the embryoconch. Centred vertical sections (which cut through the embryoconch), show a gradual increase in the height of the equatorial chambers, as seen in Figure 7D, regardless of the arrangement of those chambers in equatorial section. Uncentred vertical sections, however, give information as to the arrangement of the equatorial chambers. Examples are given in Figures 7A-C. Figure 7A illustrates a form where F = 1 or 2, that is, where the equatorial chambers have either an intersecting curve or a circular concentric arrangement; in this case the height of the equatorial chambers gradually increases towards the test periphery and is similar to that of Figure 7D. Figure 7B illustrates a form where F = 3, that is, where the equatorial chambers are in a polygonal concentric arrangement; in this case the height of the equatorial chambers rapidly increases and then remains constant towards the periphery. Figure 7C illustrates a form where F = 4 or 5, that is, the chambers are a stellate arrangement; in this case the height of the equatorial chambers fluctuates, giving an undulating effect as the rays intersect the plane of the section. Thus, by estimating the numbers of the various categories present, a value for parameter F can be estimated. Illustrations of the various arrangements of the equatorial chambers are given by Chaproniere (1980, fig. 12).

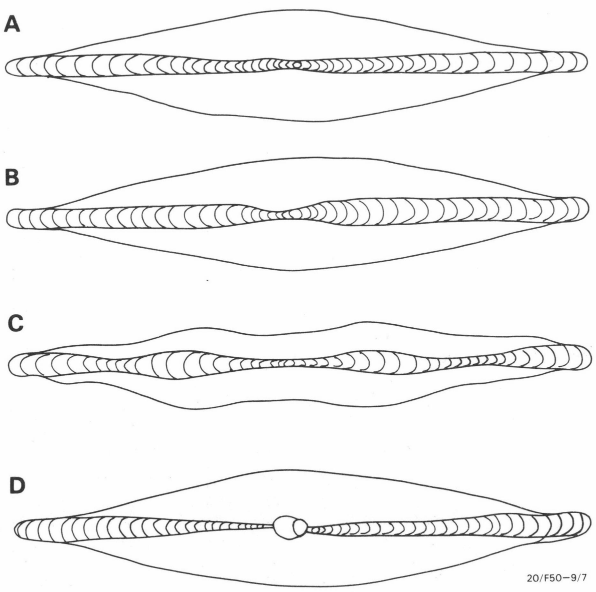

Figure 7. Diagrammatic off-centred vertical sections of *Lepidocyclina (Nephrolepidina)*, to illustrate a method by which values for parameter F can be estimated.
In A, F = 1 or 2; B, F = 3; C, F = 4 or 5; D, median section through embryoconch, from which no information on the values of F can be obtained.