

A RECONSIDERATION OF THE EAST INDIAN  
LETTER CLASSIFICATION OF THE TERTIARY

BY

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By C. G. ADAMS

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## ABSTRACT

THE East Indian Letter Classification of the Tertiary is re-examined and extended to cover the entire Indo-West Pacific region between latitudes 40°N. and 40°S. Carbonate sediments spanning the interval Upper Palaeocene to Recent are used to indicate where faunal assemblages typical of each Letter Stage have been found. Problems of regional correlation, facies, and stage boundaries are discussed. The ranges of the known marker foraminifera are plotted, and are considered individually in the text.

## I. INTRODUCTION

The Letter Classification is a means of dividing the Tertiary of the East Indies into a number of parts or "stages", each of which is characterized by an assemblage of larger foraminifera. In its original form, six main divisions were recognized (van der Vlerk & Umbgrove 1927). These were subsequently increased to eight (Leupold & van der Vlerk 1931), but later were once again reduced to six (van der Vlerk 1955). Tertiary *a* is the oldest division and Tertiary *h* the youngest; they are usually written *Ta*, *Tb*, etc. This rather broad classification was improved by dividing certain stages into numbered parts corresponding to the ranges of species or to the occurrence of particular generic assemblages. Tertiary *e* was divided into five parts (*Te*<sub>1-5</sub>) by



Leupold & van der Vlerk, largely on the supposed ranges of species of *Spiroclypeus*. Unfortunately, these early attempts at refinement proved premature since the ranges of the various species had not then been established satisfactorily. Later workers such as Rutten (see van Bemmelen 1949 : 87), Mohler (1949) and Eames *et al.* (1962) produced their own versions of the Letter Classification and in so doing helped to improve the original scheme, but no one has re-examined the premises on which the classification was based or has tried to put it on a firmer foundation.

The Letter Classification was erected because of difficulties encountered when the conventional stage terminology of Europe was applied to successions in the Far East. These difficulties arose because the molluscan and foraminiferal faunas were different in the two regions. The faunas of the tropical and subtropical Indo-Pacific proved to be richer and more varied than those of Europe and the Mediterranean, particularly in post-Eocene times. There were, however, enough similarities between the faunas for broad correlations to be possible (thus it was soon realized that  $Ta/b = \text{Palaeocene} + \text{Eocene}$ , and that  $Tb$  alone = Upper Eocene), although the dissimilarities caused great confusion at stage level.

The Letter Stages have never been typified by strata, and although Leupold and van der Vlerk indicated the main areas and sections in which the stage faunas had then been recognized, they did not suggest that one locality was more important than another for defining any particular stage. It is now known that the foraminiferal faunas of the East Indies are not peculiar to the area but are widespread over the entire Indo-West Pacific, which region, for the purpose of this paper, is defined as comprising the Indian Ocean and its bordering lands, the East Indies, the western seaboard of the Pacific Ocean and the Pacific Isles between 40°N. and 40°S. There is no virtue in considering the Letter Classification only in the context of the East Indies, especially as some divisions of the Tertiary are poorly developed in that area.

A decade ago, it seemed probable that the Letter Stages could be correlated fairly accurately with the European stages, and some workers (e.g., Glaessner 1959) felt that the Letter Classification had outlived its usefulness. At that time most stratigraphers were using only a limited number of the available European stage names, and there appeared to be a wide measure of agreement regarding their meaning. Thus, Aquitanian and Burdigalian were thought to be synonymous with Lower Miocene (Eames *et al.* 1962). The fact that the stratotypes of many European stages (e.g., Aquitanian and Burdigalian) contained no larger foraminifera in common with their supposed age-equivalents in the Far East was overlooked as it was thought that a satisfactory inter-regional correlation was possible by means of faunas known from the Middle East. The advent of correlation by planktonic foraminifera changed this view. Following a series of papers by authors such as LeRoy (1952) and Blow (1956), a zonal scheme for the Tertiary, founded on planktonic foraminifera, was proposed by Bolli (1959). This zonation, although based on the faunas of Trinidad, was soon seen to be of world-wide importance. Within a short time, stratotype sections in Europe were being re-examined for planktonic foraminifera, and strata typical of the Letter Stages were reinvestigated in the Indo-Pacific. The results were not always immediately helpful. Certain European sections were found to be barren of plankton (e.g., the type Helvetian) or to contain only restricted planktonic



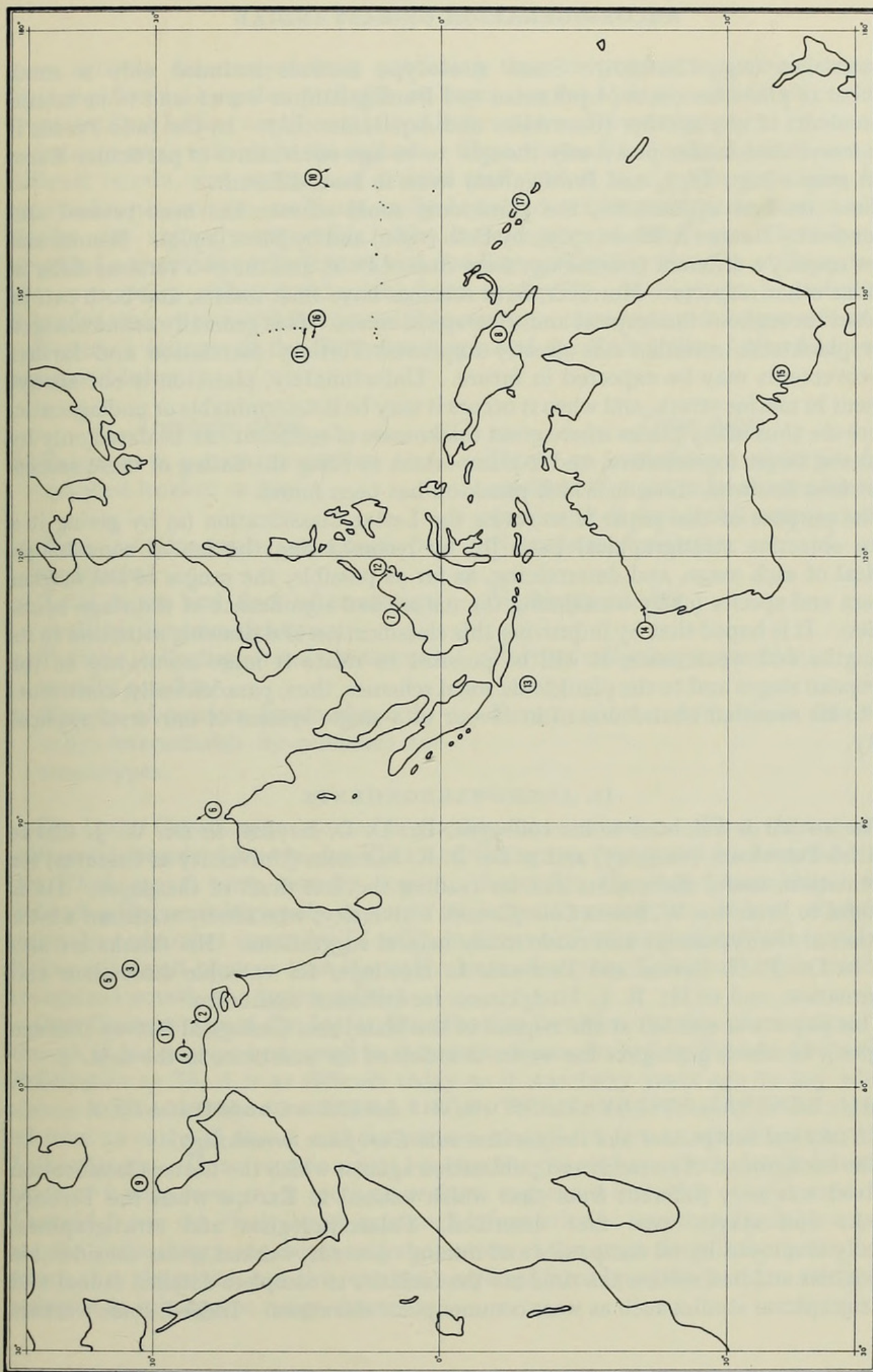


FIG. 1. Map showing the relative geographical positions of the successions illustrated in Figure 2.



assemblages (e.g., Chattian). Some stratotype sections included only a small number of plankton zones (Aquitanean and Burdigalian) or were found to be lateral equivalents of one another (Bormidian and Aquitanean *s.l.*). In the Indo-Pacific it was found that faunas previously thought to be age-equivalents of particular European stages (e.g.,  $Tf_{1-2}$  and Burdigalian) were, in fact, different.

Since its first appearance, the planktonic zonal scheme has been revised and extended by Banner & Blow (1965), by Bolli (1966) and by Blow (1969). Banner and Blow employ a different terminology from that of Bolli, and the two versions differ in various other respects. However, both schemes have their merits, and both can be applied throughout the tropical and subtropical zones. It is generally acknowledged that planktonic zonation has greatly improved Tertiary correlation and further improvements may be expected in future. Unfortunately, plankton is not always present in marine strata, and when it occurs it may be indeterminable or undiagnostic. There are thus many places where great thicknesses of sediment can be dated only by means of larger foraminifera, and it is important to bring the dating of these successions into line with those in which plankton has been found.

The purpose of this paper is to revise the Letter Classification (a) by giving it a more objective stratigraphical basis (b) by reconsidering the faunal assemblages typical of each stage, and determining, as far as possible, the ranges of the marker genera and species (c) by considering the nature and significance of the stage boundaries. It is hoped that by improving this classification and drawing attention to its strengths and weaknesses, it will be possible to relate it more accurately to the European stages and to the planktonic zonal schemes, thus, paradoxically, contributing to its eventual abandonment in favour of a single system of universal applicability.

## II. ACKNOWLEDGEMENTS

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## III. GENERAL OBSERVATIONS ON THE LETTER CLASSIFICATION

### (a) *Historical background and comparison with European terminology*

The background of research and publication against which the Letter Classification evolved was very different from that which existed in Europe when the Tertiary epochs and stages were first described. Palaeontologists and stratigraphers, usually employed by oil companies and mining concerns, worked under considerable difficulties and had neither the time nor the facilities to complete detailed faunal and stratigraphical studies such as were commonplace elsewhere. Indeed, some workers



were actively discouraged from publishing their results for commercial reasons. Papers published by palaeontologists in Europe on the basis of material sent to them from the East Indies, usually contained little or no useful stratigraphical information—for none was available to the authors. The arduous field conditions in the tropics, difficult terrain, and shortage of trained staff, meant that problems arising from reconnaissance surveys could not easily be solved, whilst verification of anomalous results was virtually impossible. The introduction of the Letter Classification, provided a simple but effective way of dividing up Tertiary time by utilizing fossils that even non-specialists could quickly learn to identify, and despite its imperfections, it has for many years satisfied a need that could not have been met in any other way.

The main features of the European stages and the East Indian Letter Stages are compared below.

<i>European stages</i>	<i>Letter stages</i>
1. Based on a section or sections in a specified locality or area.	Based on assemblages of larger foraminifera thought to be characteristic of particular divisions of Tertiary time.
2. Type sections were, or could be, designated.	No type sections exist.
3. Total fauna and flora of stratotype available for investigation.	Nothing available.
4. Further collecting from stratotypes usually possible.	Further collecting impossible.
5. Ranges of marker fossils theoretically determinable by reference to stratotypes.	Ranges not determinable in this way.

The Letter Classification worked in practice for two reasons. First, the sequences of faunas recognized by van der Vlerk and Umbgrove (1927) and by Leupold & van der Vlerk (1931) were broadly correct. Secondly, the stage assemblages were defined quite unambiguously in terms of larger foraminifera. It was, therefore, quite clear what was meant by *Td* or *Tf*<sub>3</sub> in terms of the foraminiferal fauna, whereas it was not at all obvious how the equivalents of certain European stages could be recognized outside the type localities.

One disadvantage of the Letter Classification has been the size of its units. Although it has always been easy to determine faunas including *Biplanispira* and/or *Pellatispira* as *Tb*, it is as difficult today as it was forty years ago to say whereabouts in *Tb* such faunas are situated. A late *Tb* fauna cannot readily be distinguished from an early *Tb* fauna, and the same is true of the faunas of most of the other Letter Stages. This situation exists because few people have given detailed descriptions of faunas from thick sections or from sequences including stage boundaries. Leupold & van der Vlerk (1931) gave such information as was then available regarding the sedimentary sequences and the nature of the stage boundaries in the areas which they described, but this was not amplified later by other workers, nor was it reflected in subsequent range charts.



*(b) Difficulties of inter-regional correlation*

The main problems encountered in correlating strata in the Indo-Pacific region, Europe and America may be summarized as follows:

1. The larger foraminifera of the Tethyan, American and Indo-West Pacific regions, although broadly similar, are sufficiently different in detail to make direct comparisons difficult. For example, the Upper Eocene of the Indo-West Pacific is characterized by the presence of *Asterocyclina*, *Biplanispira*, *Discocyclina*, *Nummulites*, *Pellatispira*, and *Spiroclypeus*, whereas strata of the same age in the Americas contain an abundance of *Asterocyclina*, *Lepidocyclina*, and *Helicolepidina*. Of these, only *Asterocyclina* and *Nummulites* (represented by a single Upper Eocene species in the Americas) are common to the two regions. For commentaries on provincialism in larger foraminifera see Cole (1960), Adams (1967) and references therein.

2. Stratigraphers are not yet agreed upon the relative positions and importance of all the European stages, some of which contain few, if any, larger foraminifera.

3. The Tertiary succession in north-west Europe is very thin compared with that in the Far East. It was deposited in a series of disconnected or poorly connected basins, and as much time may be represented by diastems as by fossiliferous sediments. Many important stages, e.g. Aquitanian, are not fully developed in marine strata.

4. From about Middle Miocene times onwards, the shrinking Tethys, of which Europe formed the northern margin, was not in direct connection with the Indo-Pacific, and the faunas in the two areas developed differently (see Adams 1967).

The prerequisites for a successful correlation between the Letter Stages and the European and American stages can also be summarized. They are:—

1. A generally accepted planktonic zonal scheme, applicable with minor local modifications only, within the latitudinal belt 45°N.–45°S.

2. An agreed sequence of stages in Europe, adequately defined both in terms of rock units and faunas—particularly their planktonic faunas.

3. Determination of the ranges of the age-diagnostic larger foraminifera in the Indo-Pacific and their correlation with the planktonic zonal scheme.

*(c) The facies problem*

The distribution of large foraminifera is influenced by facies to the same extent as other marine invertebrates, and one reason for choosing limestone successions for this study was to minimize the effect of environmental changes as far as possible. Even so, it is well known that marine carbonates accumulate under a wide variety of conditions and any changes affect the faunal composition of the sediments. These effects should not be under-estimated.

There are at least four main types of carbonate environment in which larger foraminifera occur:

1. Open-shelf. All depths down to the local base of the photic zone, a limiting factor for symbiotic algae which exist in the cytoplasm of some living foraminifera and for the calcareous algae which make up a considerable part of most Tertiary limestones.

2. Reefs. These faunas are rather specialized, and when *in situ* are readily



recognizable for obvious reasons. Recent reefs typically yield *Marginopora*, *Calcarina*, and encrusting genera in considerable abundance. Few true Tertiary reef faunas have been described.

3. Fore-reef shoals. Such deposits form extensively on the continental shelves and occupy a very narrow zone round the sides of atolls.

4. Back-reef environments (lagoonal). Shallow, sheltered water in an atoll or behind fringing or barrier reefs.

It is probable that most so-called fore-reef and back-reef assemblages (Pacific Isles excepted) are nothing more than accumulations of shells under typical open-shelf conditions, the fore-reef assemblages representing rougher and deeper water than those of the back-reef. There are no clear-cut distinctions between the different kinds of assemblage which tend to grade laterally into one another. Reef, littoral, and shoal faunas can become mixed by penecontemporaneous reworking—usually the movement of empty shells down the shelf or reef slope into deeper water. Larger foraminifera are sometimes found mixed with planktonics in the fine-grained basinal facies, and there are all gradations from fore-reef shoal to basinal deposits (Henson 1950). Larger foraminifera are also found in some deep-water carbonate turbidites, e.g., the Selidong Limestone, Sarawak (Adams & Wilford; in press), but here, despite their large numbers, they are very obviously redeposited.

The difficulties of correlating and dating different kinds of Cretaceous and Tertiary sediments in the Middle East have been highlighted by the work of Henson (1950) and van Bellen (1956). These authors were concerned with interdigitating open shoal, fore-reef, reef, and back-reef faunas. This problem has so far been less acute in the Far East where reef and back-reef faunas are less well known.

The genera and species shown on the range chart (Figure 3) as characterizing the various Letter Stages represent a variety of environments and are never all found together. For example, in Tertiary *a* it is common to find limestone assemblages made up largely of *Nummulites* and *Discocyclus* while others consist exclusively of *Fasciulites*, *Orbitolites* and miliolids. The composition of these assemblages is controlled by environmental factors—in this case almost certainly by water depth. It is generally believed that the *Nummulites*/*Discocyclus* assemblage represents somewhat deeper water than that containing *Fasciulites* and *Orbitolites*. As might be expected, the two assemblages grade into one another.

In Tertiary *d* and *e*, the *Austrotrillina*/*Borelis*/*Peneroplis* assemblage invariably marks back-reef conditions while the *Heterostegina*/*Lepidocyclus* (*Eulepidina*) assemblage is more characteristic of open water, fore-reef environments.

In Recent seas, *Alveolinella*, *Marginopora* and *Sorites* are typical of shallow water (littoral and/or reef flats) whereas assemblages containing an abundance of *Cycloclypeus* indicate much deeper water. Examples could be multiplied, but these few suffice to demonstrate the importance of environment and facies.

The faunas mentioned above are all well known, and their stratigraphical and ecological significance is understood. But there is a danger that some fossils currently regarded as good stratigraphical markers may, in fact, be hitherto unrecognized facies fossils. Cole (1963) quoted Schlanger's unpublished suggestion that *Heterostegina borneensis* is such a fossil and that its occurrence in the Maemong



Limestone (Te) of Guam is without much stratigraphical significance. Schlanger argued that the *Heterostegina*/*Lepidocyclina* assemblage was characteristic of a fore-reef environment whilst *Miogypsinoides* and *Miogypsina* indicated shallow water, near-reef conditions. This hypothesis, as Cole showed, was hardly tenable even on the evidence from Guam and Saipan where good stratigraphical sections are lacking; it is firmly contradicted by the successions in Borneo (e.g. Melinau Limestone) where *H. borneensis* appears well before *Miogypsinoides* and *Miogypsina*, and where facies changes cannot be invoked as an explanation. This does not mean that Schlanger's idea was wholly wrong. Indeed, it seems probable that during the limited period of their co-existence the Te *Heterostegina*/*Lepidocyclina* and *Miogypsinoides*/*Miogypsina* assemblages had a similar relationship to that of *Discocyclina*/*Nummulites* and *Fasciolites*/*Orbitolites* in Tb. Nevertheless, there can be no doubt that *H. borneensis* appeared well before *Miogypsinoides* and *Miogypsina*, and that their relationship was not simply one of mutual exclusion.

Although Cole (1963) did not accept Schlanger's suggestion that *H. borneensis* is a facies fossil and an unreliable marker for Lower Te, he subsequently suggested that difficulties in dating the middle part of the Bikini and Eniwetok successions could be accounted for by invoking facies (environmental) changes. He considers that the virtual absence of *Cycloclypeus* and the rarity of *Miogypsina* and *Lepidocyclina* in beds of Tf age could indicate an environment "totally unfavourable for *Cycloclypeus* and not too favourable for the other two genera". If this is so, it is necessary to explain the absence of markers such as *Alveolinella* and/or *Flosculinella* (depending on the age of the beds), peneroplids, *Marginopora*, etc. It is also necessary to ask why this part of the succession is so thin compared with the rest, if the whole of Tf, Tg and Th is represented.

Since the various kinds of carbonate sediments are not equally well developed in all parts of the Indo-Pacific region, it follows that knowledge of the assemblages characteristic of each environment is limited to those areas where the appropriate sediments occur. Reef and back-reef (lagoonal) facies seem to have been deposited less widely than the open shoal type, and it is predictable that the ranges of the individual genera and species which make up these assemblages will tend to lengthen as knowledge increases, while the ranges of those forms typical of the commoner types of limestones will remain fairly stable.

#### IV. REMARKS ON THE STRATIGRAPHICAL CHART AND RANGE CHART

##### (a) *The stratigraphical chart (Figure 2)*

This chart shows representative carbonate sequences containing larger foraminifera typical of the Letter Stages. Limestone successions have been illustrated because they are typically richer in larger foraminifera, are less affected by facies changes, and are generally better exposed than age-equivalent non-carbonate sediments. A few successions in argillaceous sediments, e.g. the Patala Shales of Pakistan, have been included because their faunas are better known than those of comparable limestones. Although these sections are believed to be the best described in the region at present, they are not necessarily the thickest or the most fossiliferous, and some future discoveries may well prove superior for purposes of regional correlation. Wherever



possible, sequences known to include stage boundaries have been selected. Some well-known and adequately described successions have been omitted because their inclusion would duplicate information already given without adding anything new. The relative geographical positions of the successions are shown on Figure 1.

Owing to the inadequacy of stratigraphical and palaeontological information at and near most of the stage boundaries, it is difficult to correlate strata exactly within a stage. Thus, it is not certain that the Nammal Shales ( $Ta_2$ ) of Pakistan are the exact time equivalents of the Meting Limestone although they appear to be, or that the Tulki Limestone (Lower Tf) of West Australia is precisely equivalent to the Bonya Limestone of Guam.

It is not intended that any of the successions shown here should be considered as type sections for the Letter Stages. They are, however, typical sections, i.e. places where faunas characteristic of the various stages have been found and described.

### 1. *The Dunghan Limestone*

The only description of this important succession which comprises 1,215 feet of Upper Cretaceous, Palaeocene and Lower Eocene beds at Dunghan Hill, is that of Davies (1941b). The samples on which Davies' brief account was based are deposited in the British Museum (Natural History), together with those from Mehrab Tangi where a 1,200 foot sequence of Upper Ranikot Limestone is said to occur.

### 2. *The Meting area*

The stratigraphy and larger foraminifera of the Laki Series were described by Nuttall (1925), and the thicknesses quoted here are those he gave for the succession three miles south of Meting. The foraminiferal faunas of the type Laki, about 190 miles N.N.E. of Meting, have never been described. Haque (1959) tried to show that the smaller foraminifera from the Meting Limestone indicated a Lutetian age, but Hottinger (in press) has recently dated the alveolines as Ilerdian.

### 3. *The Punjab Salt Range*

For details of the general succession and faunas see Nagappa (1959a and references therein). The unconformity shown on Figure 2 is deducible from the faunal change that occurs at the top of the Patala Shales (see Davies & Pinfold 1937). It is worth noting that Nagappa, Davies & Pinfold, and Haque (1956) all disagree about the thicknesses of the various lithological units from the Dhak Pass Beds upwards. Davies and Pinfold illustrate an unconformity between the Patala Shales and the Nammal Shales, whereas Haque shows the succession as continuous and conformable. McGowran (1968) pointed out that Haque's paper proves that a large part of the Nammal Shales must be Palaeocene in age. However, the implications of this are so important for regional stratigraphy that the section should be looked at again, and the anomalies explained, before it is used as a basis for any major correlation.

### 4. *The Khirthar Range*

The general succession was described by Vredenburg (1909) and the foraminiferal fauna of the Khirthar Series by Nuttall (1926 c & d). See pp. 102-103.



### 5. *The Kohat area*

The information for this sequence is taken from Eames (1952) and Nagappa (1959a).

### 6. *The Siju Limestone, Assam*

A general description of the Tertiary sequence and faunas of Assam may be found in Nagappa (1959a). Only the Siju Limestone, described by Ghosh (1954) and Samanta (1963) is shown here, as this part of the succession was once thought to be critical for the Ta/Tb boundary. It is now known to fall entirely within Ta (Samanta 1968a).

### 7. *The Melinau Limestone, Sarawak*

This is one of the most complete mid-Tertiary carbonate successions yet to be described from the Far East (Adams 1965). The following additional information on the sequence was obtained as a result of a field study made in 1966.

a. *Biplanispira*, a genus not reported in 1965, has been found at a very high level in the Tb part of the Melinau Gorge succession. This means that about 200 feet of limestone between Tb and Tc is devoid of age-diagnostic fossils, not 300 feet as stated previously.

b. *Spiroclypeus vermicularis* does not appear until about half way through the Tb succession.

c. A disconformity, visible in the field, occurs between Tc and Td. This accounts for the relative thinness of Td, the lower part of which is missing.

d. In 1965 it was stated that *Miogypsinoides complanatus* occurred throughout Lower Te. However, the records on which this range was based have since been checked and found to be erroneous. This species is, in fact, unknown from Melinau.

e. Random sections of the topmost beds of the limestone exposed in the Terikan River show a planktonic fauna including *Globigerinoides* cf. *quadrilobatus trilobus*, *G. sicanus* and *G. cf. altispira*, an indication that they probably belong to Bolli's *insueta* Zone (early part of Blow's Zone N8) and are somewhat younger than was thought previously.

f. *Heterostegina borneensis* van der Vlerk appears well below the first occurrence of *Miogypsinoides* (M. cf. *bantamensis*) and *Spiroclypeus*. This has been confirmed by careful collecting at close intervals in the Melinau Gorge.

### 8. *The Chimbu limestones, New Guinea*

The general succession was described, and the fauna listed but not figured, by Rickwood (1955). These limestones are interesting because they comprise a considerable thickness of Tertiary c with subordinate Upper Te beds above. A detailed study of closely spaced samples from this succession would be well worth while. Some of Rickwood's foraminiferal determinations are certainly incorrect.

Present evidence suggests that in Papua at least, Lower Te faunas are poorly represented.

### 9. *The Asmari and Gach Saran Formations, Iran*

Important descriptions of the Asmari Limestone have been given by Thomas







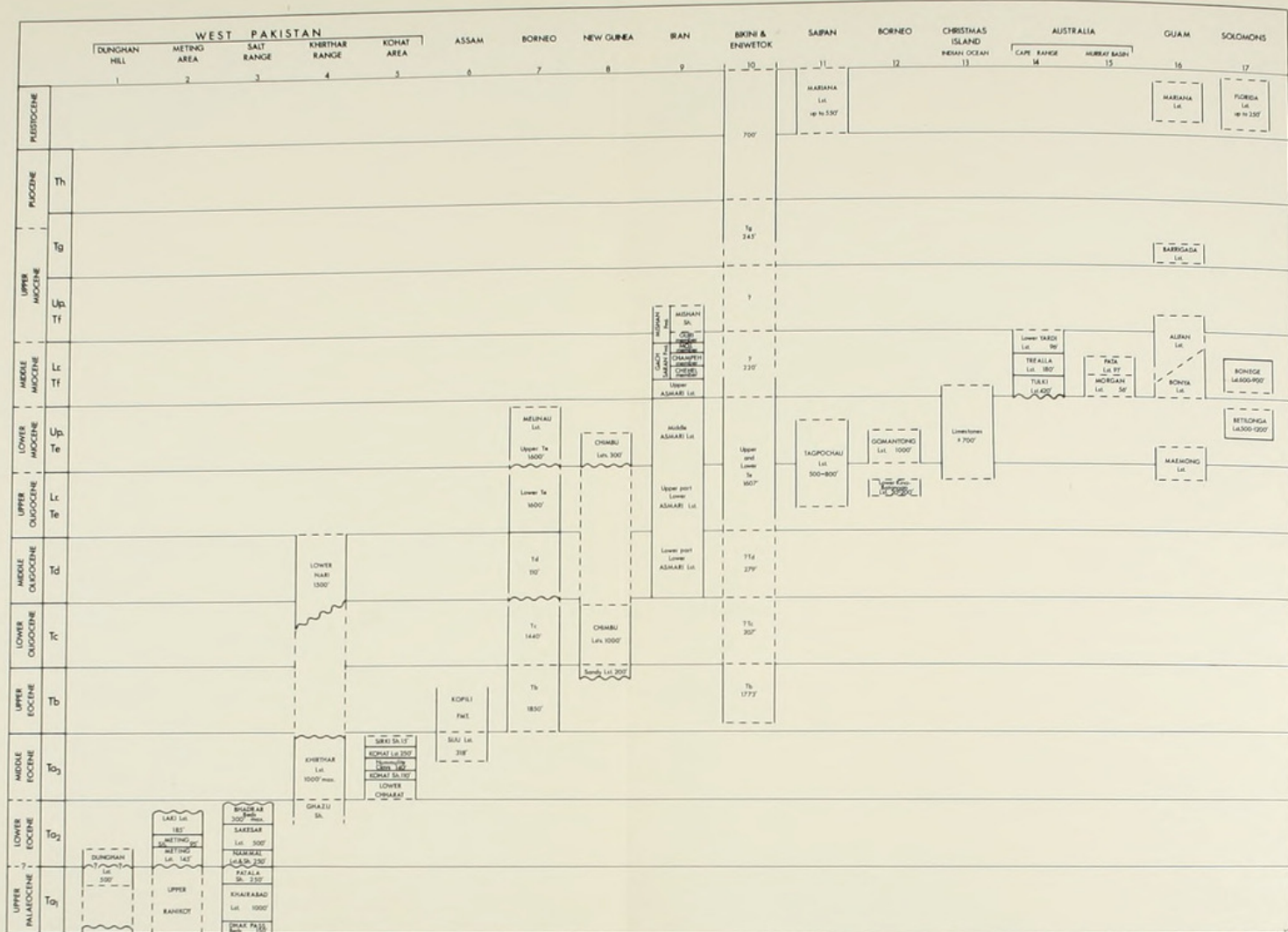


FIG 2



(1950), Kent, Slinger & Thomas (1951), Eames *et al.* (1962) and James & Wynd (1965). Thomas reported, but did not figure or describe, *Cycloclypeus* and *Spiroclypeus* from surface outcrops (Tangi-i-Gurguda) at the base of the limestone. These records have never been confirmed although they were repeated by James & Wynd. If correct, they would have an important effect on mid-Tertiary correlation in the area.

James & Wynd listed (p. 223) the following foraminifera from the Champeh and Mol Members of the Gach Saran Formation: *Borelis melo*, *Flosculinella*, *Miogypsina*, *Peneroplis farsensis* and *Taberina malabarica*; and *Flosculinella* cf. *bontangensis* from 480 feet above the base of the laterally equivalent Rajak Formation. *F. bontangensis*, *Borelis melo*, *Operculina complanata* Defrance, *Nephrolepidina*, *Taberina malabarica* were listed from the base of the overlying Mishan Formation (Guri Limestone Member). Only *Miogypsina* sp., *Nephrolepidina* sp. and *Operculina complanata* were figured. These assemblages are characteristic of Lower Tf and, if the species are correctly identified, prove a direct sea connection with the Indian Ocean.

#### 10. Bikini and Eniwetok atolls

A composite section compiled from the data provided by Cole (1954, 1958), Todd & Post (1954) and Todd & Low (1960) is illustrated here. The maximum thickness quoted for each Letter Stage in the drill holes on the two atolls has been used.

As Cole himself observed, it is questionable whether Tc/d beds are really represented in these holes. No diagnostic fossils have been found and the dating rests purely on negative evidence. Tertiary *b* is well represented in the Eniwetok bores but was not penetrated on Bikini.

Tertiary *e* is present in the cores from both atolls, and at Bikini both Upper and Lower divisions were recognized by Cole. Tertiary *f* is a problem. Cole assigned a maximum of 350 feet of limestone to this division, basing his dating on the occurrence of *Cycloclypeus indopacificus vandervlerki* and *Lepidocyclina orientalis* in Eniwetok, and on the latter species only in Bikini. However, no absolutely diagnostic Upper Tf species were found. Adams (1968) noted that the specimens referred by Cole (1954 : 258) and by Todd *et al.* (1954, 1960) to *Austrotrillina howchini* should really have been assigned to *A. striata*, a Te species, and it now seems very probable that Tertiary *f*, if it occurs at all, is represented only by the lowest levels of Lower Tf, and that a disconformity separates the oldest Miocene horizons from the overlying Pliocene. No diagnostic Middle or Upper Miocene planktonic species were reported from these drill holes.

#### 11. Saipan

The geology and larger foraminifera were first described by Cole & Bridges (1953), further extensive accounts being given by Cole (1957) and Hanzawa (1957). Unfor-

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FIG. 2. Representative sections through described successions, mainly carbonates, ranging in age from Palaeocene to Recent. For details see pp. 94-99. Precise correlation of all the limestone units within each Letter Stage is not at present possible. The correlation between the Letter Stages and the Epoch/Sub-Epoch names for the Cainozoic reflects the writer's current opinion and is only to be regarded as approximate.



tunately, owing to the nature of the terrain, the samples on which these accounts were based were not collected in any known stratigraphical order, and the results have to be interpreted in the light of knowledge derived from better exposed successions elsewhere. The smaller foraminifera of the island were described by Todd (1957).

12. *The Kinabatangan and Gomantong limestones, Sabah*

The numerous small Upper and Lower *Te* limestones along the lower course of the Kinabatangan River in Sabah, Borneo, along with the much larger Gomantong Limestone, have been studied by the writer and the results are now being prepared for publication. They confirm the faunal sequence described from the Melinau Limestone, Sarawak.

13. *Christmas Island (Indian Ocean)*

The so-called Miocene orbitoidal limestones were first described by Jones & Chapman (1900). Nuttall (1926a) revised the Orbitoids, and Ludbrook (1965) described the fauna from a few additional samples. The whole of the post-Eocene limestone succession has recently been carefully resampled along several traverses by D. J. Belford who, together with the writer, is preparing a description of the faunal succession. It is sufficient to state here that the lower part of the limestone (approximately 250 feet) is Lower *Te* in age, whilst the rest, apart from the uppermost 50 feet or so, is Upper *Te*. The highest beds can be dated as Lower *Tf* on the presence of *Flosculinella bontangensis*. It is interesting to note that such well-known "species" as *Eulepidina ephippioides* and *E. andrewsiana*, for both of which Christmas Island is the type locality, come from the lower part of *Te*.

14. *The Cape Range limestones, Western Australia*

This sequence includes four limestones, all of which were described by Crespin (1955). The Trealla and Tulki limestones contain good Lower *Tf* faunas but the underlying Mandu Limestone is more difficult to date. The type section for the Mandu Limestone contains a fauna which suggests a Lower *Te* age, but additional species listed by Crespin from nearby localities indicate that the age is more probably Upper *Te*. In view of this uncertainty, the Mandu Limestone is omitted from the chart. There is, in any case, a disconformity between the Mandu (*Te*) and Tulki (*Tf*) limestones as was recognized by Crespin.

15. *The Morgan and Pata limestones, Murray Basin, South Australia*

The stratigraphy and fauna of the limestones in the Murray Basin were described by Ludbrook (1961). The Pata Limestone is important in the present context because it contains *Austrotrillina howchini* in association with *Orbulina universa*. The thicknesses shown in Figure 2 are for the type sections of the Morgan Limestone (including the Cadell Marl Lens) and for the standard subsurface section of the Pata Limestone.



16. *Guam*

The stratigraphical succession and faunas were described by Cole (1939, 1963) and Todd (1966). Unfortunately, the samples from which the micro-faunas were described could not be collected in stratigraphical order, and in places the sequence is not very well understood.

The youngest carbonate on the island, the Mariana Limestone, was assigned to the Pleistocene by Cole and by Todd. It contains *Baculogypsina sphaerulata*, *Calcarina spengleri*, *Cycloclypeus carpenteri*, *Heterostegina suborbicularis*, and *Marginopora vertebralis*. Similar faunas occur at the same level in Saipan.

The Barrigada Limestone contains *Cycloclypeus postindopacificus*, *Operculina lucidisutura* and *O. rectilata*, and was dated as Tg by Cole. In this paper *C. postindopacificus* is not distinguished from *C. carpenteri*. Cole's age determination depended on the presence of *O. lucidisutura* and *O. rectilata*, species which he had previously reported from Bikini and Eniwetok.

Strata mapped as part of the Alifan Limestone contain *C. carpenteri*, *M. vertebralis*, *Heterostegina suborbicularis* and, at lower levels, *Miogypsinoides cupulaeformis* and *Rotalia atjehensis*. Cole's suggestion that the lower horizons can be correlated with the Bonya Limestone is reasonable.

The Bonya Limestone contains cycloclypeids which have been referred to *C. (K.) annulatus*, *C. indopacificus* and *C. posteidae*, together with *Flosculinella bontangensis*, *Nephrolepidina japonica*, *N. rutteni* and *Marginopora vertebralis*, an assemblage clearly denoting a Lower Tf age. *Miogypsinoides cupulaeformis* and *Nephrolepidina sumatrensis* are also present. This appears to be the only well-documented record of *Miogypsinoides* in strata of Lower Tf age.

The Maemong Limestone is divisible into two parts: an upper portion with *C. eidae*, *Eulepidina ehippioides*, *Spiroclypeus higginsii*, *Miogypsinoides dehaarti*, *N. sumatrensis*, and *N. verbeeki* (an assemblage indicative of Upper Te), and a lower portion with *Heterostegina borneensis*, *Eulepidina ehippioides*, *Miogypsinoides bantamensis*, *Nephrolepidina sumatrensis* and *Spiroclypeus yabei* (an assemblage indicative of late Lower Te).

17. *Succession in the Solomon Islands*

Coleman (1963) described the stratigraphy and foraminiferal faunas of these islands. A few of the limestones are shown on Figure 2; the remainder only repeat the faunas found in successions elsewhere in the region and are not included.

(b) *The Range Chart (Figure 3)*

The genera and species shown on this chart are those for which the most reliable stratigraphical data are available. Many species of potential stratigraphical importance have been omitted because their ranges cannot be determined at present or because they have so far been described from one locality only. Some important species are known only from isolated samples, e.g. *Lacazinella wichmanni*. These are included only when they can be dated accurately from the associated fauna.

The ranges shown on this chart can be checked by reference to the carbonate



sequences shown in Figure 2, or, in the case of species like *L. wichmanni*, by reference to the relevant notes in the text.

Solid lines indicate that ranges are well established and verifiable, usually by reference to one or more of the successions shown in Figure 2 ; broken lines indicate a degree of uncertainty. Thus, *Heterostegina borneensis* is represented by a solid line throughout the upper part of Lower Te where it can be proved to occur, and by a broken line through the lower part of this division where proof is lacking although records exist. Species represented only by broken lines have not, of course, been described from any of the successions shown on Figure 2.

Although this paper is based primarily on larger foraminifera, certain smaller benthic and pelagic genera (e.g., *Austrotrillina*, *Halkyardia* and *Orbulina*) are included as they are readily determinable in random sections of limestone.

#### V. NOTES ON THE STAGES AND STAGE BOUNDARIES

Very few adequately described sequences include stage boundaries, and there are even fewer in which sedimentation can be shown to have been continuous from one stage to another. Stage boundaries will, of course, always be difficult to locate accurately in sections where sedimentation was uninterrupted, as in such places faunal changes are likely to be gradual rather than abrupt. In the absence of facies changes, sudden faunal alterations normally suggest discontinuities (diastems) whether or not these can be recognized in the field. Catastrophic events could produce similar effects, but such phenomena are rare.

Throughout this section, each Letter Stage is first defined in terms of genera and species which are restricted (or almost restricted) to it, or which are especially prominent in the fauna. The faunal diagnosis is followed by comments on the best known sections and localities, and on areas which may in future prove to include good examples of the stage faunas.

#### Tertiary $a_1$ (late Palaeocene)

DIAGNOSTIC FAUNA : *Actinosiphon punjabensis*, *Assilina dandotica*, *Discocyclina ranikotensis*, *Fasciolites* (including *F. vredenburgi*), *F. (Glomalveolina)*, *Lockhartia* spp., *Miscellanea miscella*, *Nummulites nuttalli*, *N. spp.*, *Operculina sindensis*, *O. canalifera*, *Saudia labyrinthica*.

This fauna is virtually restricted to the Palaeocene. There are very few records of larger foraminifera from definite " Lower " and " Middle " Palaeocene sediments anywhere in the world, a reflection partly of the fact that beds of this age are rarely developed in the right facies for larger foraminifera and partly of a confusion in terminology. The introduction of the Ilerdian stage in 1960 changed the whole concept of Palaeocene for some workers.

No  $Ta_1$  sections have been described from south-east Asia although faunal assemblages of this age are known (see Liechti *et al.* 1960 and Adams 1965). Van der Vlerk & Umbgrove (1927) reported *N. nuttalli*, *N. kelatensis*, and *N. thalicus* from Borneo, but these typical Palaeocene species were thought by later authors to occur at the same level as *Pellatispira*, and their stratigraphical significance was thus obscured.

The best Palaeocene sections are in West Pakistan where the so-called " Ranikot



fauna " includes most of the genera and species listed above. According to Pascoe (1963 : 1477) the Ranikot Series in Sind " is divisible into a lower fluviatile stage, usually from 1,000–1,200 feet thick but reaching a maximum of 1,500 feet, and an upper marine stage usually 700–800 feet thick but rising to a maximum of about 1,000 feet ". The Ranikot fauna has not been described from the type section (Rani-jo-kot, Sind) in the northern part of the Laki Range where, according to Williams (1959), the beds are thick, non-marine and unfossiliferous except for plant remains, but from farther south (Nuttall 1926b) and from Thal over 500 miles to the north (Davies 1927).

#### The $Ta_1/Ta_2$ boundary

No continuous carbonate succession across this boundary has been described, and so far as is known there is a faunal break between the youngest  $Ta_1$  and oldest  $Ta_2$  larger foraminiferal assemblages everywhere in the region. In West Pakistan there are certainly localities where strata of  $Ta_2$  age rest on beds of  $Ta_1$  age (e.g., Dungan Hill and Mehrab Tangi, Baluchistan, and at Thal, N.W. Frontier Province (Davies 1927)). The Dungan Limestone includes beds of Upper Cretaceous, Palaeocene and Lower Eocene age (Davies 1941b), but the faunal sequences are either undescribed or need describing in more detail.

#### Tertiary $a_2$

DIAGNOSTIC FAUNA : *Assilina* (including *A. leymerie* and *A. granulosa*), *Discocyclina*, *Fasciolites* (including *F. globosa*, *F. oblonga* and *F. subpyrenaica*), *Nummulites* spp. (including *N. ataticus*), *Opertorbitolites douvillei*, *Orbitolites complanatus*, *Somalina*.

In the Laki Range (West Pakistan) the fossiliferous  $Ta_2$  comprises the Laki limestone (200 feet) and the underlying Meting Shale (320 feet). These are generally believed to be equivalent to the Ghazij Shales (1,960 feet thick in the type section at Spintangi, but elsewhere varying in thickness from 700 to almost 8,000 feet according to Williams (1959). The lowest beds of the Ghazij Formation may in places be Palaeocene in age but the greater part is said to be Lower Eocene. This formation is believed to be overlain conformably by the Khirthar Formation. The foraminiferal faunas from the best sections (Laki Range, Sulaiman Range etc.) are either undescribed or need describing in greater detail than has been possible hitherto. The Laki, Meting, Sakesar limestones and their equivalents have traditionally been regarded as Lower Eocene in age but this is increasingly being questioned. Haque (1956) showed that the typical  $Ta_2$  larger foraminifera of the Nammal Shales first occur well below the last occurrence of *Globorotalia velascoensis* and other supposedly good Palaeocene markers in the Nammal Gorge. Hottinger (in press) has identified several species of typical Ilerdian alveolines from the Meting Limestone. If the Ilerdian is accepted as being entirely Palaeocene in age, then there is no doubt that the Palaeocene/Eocene boundary in Pakistan will have to be raised considerably. Most of  $Ta_2$  will then be assigned to the Palaeocene. However, the writer thinks it best to defer judgement on this issue until the faunas of the area have been redescribed, and Hottinger's zonal scheme has been properly tested in the Far East.

No  $Ta_2$  carbonate sequences with larger foraminifera have yet been described from



south-east Asia or the Pacific Isles, and it is possible that this division is missing over large parts of this area. Doornink's record (1932) of Lower Eocene faunas from Java is incorrect. The beds concerned contain *Pellatispira*, a characteristic Upper Eocene genus.

#### The $Ta_2/Ta_3$ (Lower/Middle Eocene) boundary

The only described sections are in West Pakistan, but even here much detailed work remains to be done. If the faunal changes are as abrupt as the published evidence suggests (Nuttall 1926d ; Davies 1927, 1940b ; Nagappa 1959), then this boundary is probably a disconformity almost everywhere. The sudden faunal change could, on the other hand, simply reflect our inadequate knowledge of faunas immediately adjacent to the boundary.

#### Tertiary $a_3$ (Middle Eocene)

DIAGNOSTIC FAUNA : *Assilina* (including *A. spira*, *A. exponens*, *A. cancellata*), *Asterocyclina*, *Dictyoconoides cooki*, *Discocyclina* (including *D. sowerbyi*, *D. javana*, *D. dispansa*), *Fasciolites* (including *F. elliptica*, *F. wichmanni*), *Nummulites* (including *N. atacicus*, *N. carteri*, *N. gizehensis*, *N. javanus*, *N. perforatus*, *N. millecaput*), *Orbitolites complanatus*, *Somalina*.

No  $Ta_3$  section has yet been described from south-east Asia or the Pacific Isles, although isolated faunas of this age are known from Java (Doornink 1932), Timor (Henrici 1934) and New Guinea (Rutten 1936).

It has often been assumed that the very large species of *Nummulites* (*N. carteri*, *N. javanus*, *N. gizehensis*, *N. millecaput* etc.) are restricted to the Middle Eocene, but this has never been shown to be true for the whole area. Although Samanta's (1965) Upper Eocene dating for the upper part of the Siju Limestone, which contains *N. gizehensis* and *N. perforatus*, was subsequently changed to Middle Eocene (Samanta 1968a), there is still a possibility that some large nummulites range up into the early part of  $Tb$  (e.g., *N. javanus* in Borneo. Adams 1965). Some range charts suggest that the large nummulites all appeared together at the base of the Middle Eocene and became extinct simultaneously at the top, but this is highly improbable.

The Khirthar Formation in its type section (Gaj River) ranges from Middle Eocene to Lower Oligocene (Williams 1959, Khan 1967). Nuttall's descriptions (1926c & d) of the Middle Khirthar faunas were not based on continuous sampling but on isolated samples collected over a large area during a reconnaissance survey of parts of western India in 1920-21. The ranges he quotes for the larger foraminifera are, therefore, very inexact.

#### The $Ta_3/Tb$ (Middle/Upper Eocene) boundary

No described Indo-Pacific carbonate succession is known to be continuous across this boundary.

Ghosh (1954) described what he thought was the Middle/Upper Eocene boundary from the Siju Limestone in Assam, and Samanta (1962 & 1963) described the foraminiferal fauna. He, like Ghosh, assigned the lowermost 82 feet to the Middle Eocene and the uppermost 240 feet to the Upper Eocene. However, he subsequently



decided (1968a) that the specimens of *Pellatispira* on which the Upper Eocene determination mainly rested, were not true representatives of the genus. He, therefore, provisionally assigned the upper part of the limestone to the Middle Eocene, observing that its faunas could be regarded as transitional between Middle and Upper Eocene.

The limestone succession in the Khirthar Range (West Pakistan) is in need of careful study. Williams (1959) stated that the Upper Eocene in this area is developed in pelagic facies, but he did not mention the nature of its junctions with the Middle Eocene and Oligocene. Khan (1967), on the other hand, dated these beds with pelagic foraminifera as Middle Eocene.

Schweighauser (1953) described the faunas across the Lutetian/Priabonian boundary in northern Italy. Here, as in Somalia according to the work of Azzaroli (1952), the overlap of the age-diagnostic marker genera makes the exact position of the boundary a matter of opinion.

### Tertiary *b* (Upper Eocene)

DIAGNOSTIC FAUNA : *Asterocyclina* (including *A. matanzensis* Cole), *Biplanispira*, *Discocyclus* (numerous species including *D. omphalus*, *D. dispansa*, *D. sella*) *Lacazinella wichmanni*, *Nummulites fabianii*, *N. pengaronensis*, *N. chavennesi*, *Pellatispira*, *Spiroclypeus alba-pustula*, *S. vermicularis* and *Wilfordia sarawakensis*.

This stage is very well represented throughout the whole of south-east Asia and the Pacific, and its microfaunas are currently better known than those of any other part of the Palaeogene. Tertiary *b* larger foraminifera are not, however, well represented in carbonate sediments on the Indian sub-continent. The best-known sequences are in Borneo (Adams 1965), Saipan (Cole 1957, Hanzawa 1957), Somalia (Azzaroli 1952) and in the Pacific Isles (Cole 1954, 1958). Many authors have described faunas from isolated samples in different parts of the region (e.g., Java, Doornink 1932 ; Pakistan, Eames 1952 ; India, Samanta 1965) but despite this, the faunal sequence has not been properly established and the potentialities of the larger foraminifera for zoning the Upper Eocene have by no means been fully exploited. We do not know the exact range of a single species of *Pellatispira*, *Biplanispira*, *Discocyclus*, or for that matter of any species of *Nummulites*. This simply reflects a general failure on the part of authors to describe sections in detail, and can certainly be corrected in the future.

### The Tb/Tc (Eocene/Oligocene) boundary

The only known sections across this boundary are in the gorges of the Melinau and Medalam rivers in north-east Sarawak, Borneo. These two sections are five miles apart, and in both the boundary is hard to place because the faunal change is gradual (Adams 1965 and paper in preparation). As stated earlier, the Khirthar Formation in its type locality is known to range from Middle Eocene to Lower Oligocene (Williams 1959 : 390). All previous authors (also Pascoe 1963) state that there is a substantial break between the Khirthar and the Lower Nari, all the Upper Eocene being missing. Khan (1967) has shown that in the Badhra area of Sind there is a marked disconformity between the Middle Eocene and the Middle Oligocene,



at the base of which there is a limestone conglomerate. He claims that in the Gaj River succession, Lutetian-basal Auversian faunas of pelagic and benthic foraminifera (presumably those described as Upper Eocene by Williams 1959) are followed by Lower Oligocene (Lattorfian) larger foraminifera.

### Tertiary *c* (Lower Oligocene)

DIAGNOSTIC FAUNA : *Nummulites* (particularly *N. fichteli*) without *Eulepidina*. *Borelis*, *Cycloclypeus koolhoveni*, *Dictyoconus melinauensis*, *Heterostegina bantamensis*, *H. praecursor*, *Lacazinella reicheli*, *Nummulites vascus*, *N. pengaronensis*, *N. fichteli*, *Praerhapydionina delicata*.

Although Tc faunas are known to be widespread, few sequences through rocks of this age have been described. The thickest succession so far found is in the Melinau limestone, Sarawak (more than 1,000 feet). The thinner Sarang limestone, also in Sarawak, is entirely of Tc age (Adams 1964). Tertiary *c* limestones occur in New Guinea, and in the Chim Gorge (West Central Highlands, Papua) at least a thousand feet of limestone contains *N. fichteli*, *Heterostegina*, *Operculina*, etc. (A.P.C. 1961). Faunas of this age are known from the Moluccas (Bursch 1947) and from many localities in Indonesia (see van Bemmelen 1949), but described successions are lacking.

The lower part of the Nari Formation in Pakistan (about 1,500 feet thick according to Pascoe 1963 : 1618), although mainly Middle Oligocene in age, is said to be conformable with the Khirthar Formation except at the southern end of the Khirthar Range (Williams 1959) and must, therefore, include beds of Lower Oligocene age. Williams proposed that the type section should be taken as the Gaj River, presumably because the succession there is better exposed and more accessible than in the area originally mentioned by Blanford\* (1879), the Nari Nai, a river a few miles to the south. Several authors (e.g., Nuttall 1925) have described reticulate nummulites from the Nari beds, but no one has described the entire foraminiferal fauna or has examined samples collected in stratigraphical order through continuous sections. Most of the Lower Nari is of Middle Oligocene age, and in places where *Lepidocyclina* appears at the base the entire thickness must locally be assigned to the Middle Oligocene.

### The Tc/Td (Lower/Middle Oligocene) boundary

The only place where this boundary has been observed in the field is the Melinau Gorge, Sarawak. The junction there is a clearly marked erosion surface (personal observation 1966) and there is a sudden faunal change as the boundary is crossed (Adams 1965).

### Tertiary *d* (Middle Oligocene)

DIAGNOSTIC FAUNA : *Nummulites* (mainly reticulate forms, *N. fichteli*) and *Lepidocyclina* (*Eulepidina*) spp., *Borelis* (including *B. pygmaeus*), *Cycloclypeus oppenoorthi* (and, perhaps, transitional forms to *C. eidae*), *Heterostegina* spp.

\* See Medlicott & Blanford (1879).



Faunas of this age are known from East Africa (Azzaroli 1958), Iraq, Iran (Eames *et al.* 1962), West Pakistan, Borneo, New Guinea and elsewhere. However, with the possible exception of the Lower Nari Beds, no thick successions have been reported.

Only the upper part of Td is present in the Melinau limestone (Sarawak), and the most likely places for the lower part to be found seem to be in Pakistan (Lower Nari Formation) and New Guinea (New Guinea Limestone).

Tertiary *d* is defined by the association of *Nummulites* and *Eulepidina*. It seems probable that *Eulepidina* and *Nephrolepidina* appeared simultaneously in the Far East and if this can be confirmed, the association of *Nummulites* and *Lepidocyclina* *s.l.* (excluding any Eocene species) will be sufficient to identify Td.

The Tc/Td boundary, being defined on the first appearance of *Eulepidina*, is almost certainly diachronous. Since *Nummulites* and *Eulepidina* do not always occur in association, it is probable that some isolated occurrences of Td rocks containing only *Nummulites* have been recorded as Tc, while others containing only *Eulepidina* have been dated as Te.

#### The Td/Te (Middle/Upper Oligocene) boundary

The best known section is in the Melinau Gorge, Sarawak, where the faunal change is gradual and deposition was continuous between the two stages. This boundary was first described by the author (1965) and a further description based on additional material is now in preparation.

The only sections which Leupold and van der Vlerk (1931) thought were continuous across the Td/Te boundary were:—

a. In the north-central Boraë (Kalimantan) where they reported :

Globigerina mergels	Te
Lepidocyclina kalk	Td
Seilor-lagen	Tc

but the fauna from the critical part (Td/Te) of this succession was neither described nor listed.

b. In the Tidoengsche Landen (Kalimantan), *Nummulites fichteli* is said to occur in association with *Eulepidina* in the Tempilan beds (1000 metres thick), *Heterostegina* is said (p. 626) to be represented by *H. ruida* in these beds, and not by *H. borneensis* which occurs in the overlying Mesaloi marls (also about 1000 metres thick). There is, however, no published description of this faunal sequence nor of any lithological change that may occur at the boundary.

It is evident that if Td is synonymous with Middle Oligocene the Oligo/Miocene boundary must fall somewhere within Te, probably fairly near the top. There appears to be little evidence to support the widely held belief that *Miogypsinoides* and *Spiroclypeus* range down to the base of Te. Such evidence as exists (mainly from Sarawak) suggests that they appear fairly late in Lower Te, i.e. above the first appearance of *H. borneensis*.



### Lower Tertiary $e$ ( $= Te_1/Te_4$ )

DIAGNOSTIC FAUNA : *Austrotrillina striata*, *A. asmariensis*, *Cycloclypeus eidae*, *Heterostegina borneensis*, *Lepidocyclina* (*Eulepidina*) spp., *L. (Nephrolepidina) isolepidinoides*, *N. parva* (other species at high levels), *Miogypsinoides complanatus*, *M. bantamensis*, *Spiroclypeus* spp.

This stage is well developed over the whole area, the best faunas being known from Borneo (Adams 1965), Saipan (Hanzawa 1957, Cole 1957), and the Pacific Isles (Cole 1954, 1958). For many years it has been customary to equate Lower  $Te$  with early Lower Miocene on the ground that the larger foraminiferal assemblages are the equivalents of the Aquitanian of Europe, but this correlation cannot be justified. The only larger foraminifera in the stratotype Aquitanian are miogypsinids and a primitive *Heterostegina* (Drooger *et al.* 1955), and the correlation therefore depends on plankton and on larger foraminifera found in other sections. It is probable that much of the Upper Nari of Pakistan (maximum thickness 5–6,000 feet ; Pascoe 1963 : 1617) is Lower  $Te$  in age. This formation is, however, largely unfossiliferous and passes gradually into the underlying Lower Nari ( $Td$ ). See Pascoe (1963 : 1620).

### The Lower/Upper $Te$ (Oligocene/Miocene) boundary

This can be recognized over the whole of the western Pacific and throughout Indonesia. It appears to be peculiar to the Indo-Pacific Province and not to be recognizable with certainty elsewhere. In the writer's opinion, it corresponds approximately to the Oligocene-Miocene boundary in Europe. The best known sections for the study of this boundary are in Iran (Asmari Limestone), Christmas Island, Sarawak (Melinau Limestone) and New Guinea (Kereru Limestone). The New Guinea sections are believed to be well exposed but need to be re-collected and described in detail ; the Christmas Island sequence is good and is now being re-described by the writer and Dr. D. J. Belford (Bureau of Mineral Resources, Canberra). In the Melinau limestone, Sarawak, the junction is almost certainly disconformable, but it has not yet been observed in the field.

### Upper Tertiary $e$ ( $= Te_5$ )

DIAGNOSTIC FAUNA : *Austrotrillina striata* grading into *A. howchini* at high levels, *Cycloclypeus eidae* group, *Flosculinella reicheli*, *F. globulosa*, *Lepidocyclina* (*Eulepidina*), *L. (Nephrolepidina) inflata*, *N. japonica*, *N. sumatrensis* in abundance, and *N. verbeeki*, *Miogypsina* spp. (including *M. thecidaeformis*), *Miogypsinoides dehaarti*, *Spiroclypeus* spp.

Rocks of this age are also well developed over the whole province. The best-known faunas are from Borneo, Saipan, New Guinea and the Pacific Isles. The highest  $Te$  beds in the Melinau Limestone have recently been found to contain a planktonic fauna (see p. 96) almost certainly referable to Banner & Blow's Zone N8 (late *insueta* Zone of Bolli). The Lower Rembang beds of Java are of Upper  $Te$  age (van der Vlerk 1928).

### The Upper $Te$ /Lower $Tf$ (Lower/Middle Miocene) boundary

The best section so far discovered is on Christmas Island (Indian Ocean) but there



the Tf fauna is represented only by *Flosculinella bontangensis*. Better sections undoubtedly exist in New Guinea but they await description. In the Cape Range (Australia) the Te/Tf boundary is a disconformity (Crespin 1955).

The deep drill holes on Bikini and Eniwetok atolls pass through the boundary but its recognition is difficult in the absence of continuously cored material.

Leupold and van der Vlerk (1931) showed the Te/Tf boundary as occurring within the Tabellor limestones (thought to be about 600 metres thick) on the Mangkalihat Peninsula, Borneo, but the faunas from these beds have never been described and the evidence on which the boundary is based is unknown.

In Pakistan, the Te/Tf boundary must fall somewhere within the Gaj beds which, in the type locality (Gaj River) are 1,500 feet thick (Pascoe 1963) [2,020 feet according to Williams (1959 : 390)]. The basal beds of the Gaj Formation are calcareous (limestones and shales) whereas the higher beds are mainly sandstones, shales and gypseous clays. According to Vredenburg (1906) the Gaj rocks of Sind are often crowded with *Lepidocyclina marginata* (Michelotti), a species often reported from strata of Oligocene and Lower Miocene age in Europe.

#### Lower Tertiary f (= Tf<sub>1</sub>/Tf<sub>2</sub>)

DIAGNOSTIC FAUNA : *Alveolinella fennemai* auctt. (probably merely a primitive form of *A. quoyi*), *Austrotrillina howchini*, *Borelis melo*\*, *B. melo curdica*\*, *Cycloclypeus posteidae*, *C. indopacificus*, *C. (Katacycloclypeus) annulatus*, *Flosculinella bontangensis*, *Lepidocyclina (Nephrolepidina)* spp. including *N. ferreroi*, *N. sumatrensis*, *N. martini*, *N. japonica*, *N. orientalis*, *Marginopora vertebralis*, *Miogypsina* spp., *Orbulina suturalis*, *O. universa*, "*Taberina*" *malabarica*.

Limestones of this age are widespread in the Indo-Pacific region but few faunal sequences have yet been properly described. Exceptions are the successions in the Solomon Islands described by Coleman (1963) and in the Cape Range, Australia (Tulki and Trealla limestones) described by Crespin (1955). New Guinea is a most promising area for future research. Cole (1963) dated the Bonya limestone of Guam as Tf. The main part of its fauna is, however, consistent with a Lower Tf age. The Upper Rembang beds of Java are also of this age (van der Vlerk 1928).

#### The Lower/Upper Tf boundary

No good sections across this boundary are known to the writer. It may occur in the Alifan limestone of Guam and could in future be found in New Guinea.

Leupold and van der Vlerk (1931) regarded the Upper Balikpapan beds of Borneo as Tf<sub>3</sub> and the Lower Balikpapan beds as Tf<sub>2</sub>. The total thickness of these beds was given as 1,200 metres, but much of this consists of barren sandstones and coal. The limestone faunas, on which the dating depends, occur at various unspecified levels near the top and base of the succession. No descriptions of the limestones or of the faunas have been published.

\* Known from East Africa & the Middle East (Eames *et al.* 1962) but not with certainty from Indonesia and the Pacific.



### Upper Tertiary *f* (= *Tf*<sub>3</sub>)

DIAGNOSTIC FAUNA : *Alveolinella quoyi*, *Cycloclypeus carpenteri/guembelianus*, *Heterostegina* spp., *Lepidocyclina rutteni* (probably restricted to the lower part), *L. radiata*, *Lepidocyclina orientalis*, *L. talahabensis*, *Marginopora vertebralis*, *Operculina* spp. (*Orbulina* is very common in Upper *Tf* and younger limestones).

Although faunas of this age are well known, no carbonate successions of any great thickness have been found. Upper *Tf* faunas might be expected in the Bikini and Eniwetok drill holes but typical assemblages seem to be lacking. The Tji Lanang and Njalindung beds of Java are usually assigned to Upper *Tf*.

### The *Tf*/*Tg* boundary

This does not appear to have been described from a carbonate sequence or, indeed, from any other succession in which it can be recognized on the basis of larger foraminifera. Cole (1963) thought that it might occur in the Alifan limestone of Guam but the evidence for this is very weak.

### Tertiary *g*

DIAGNOSTIC FAUNA : *Alveolinella quoyi*, *Cycloclypeus carpenteri/guembelianus* and *C. postindopacificus*, *Operculinoides rectilata*, *O. lucidisutura*. The assemblage is similar to that of Upper *Tf* but lacks *Lepidocyclina*. Tertiary *g* was originally defined as "young Miocene without orbitoids" by Leupold & van der Vlerk (1931).

The Barrigada limestone of Guam has been dated as *Tg* by Cole (1963), who also thinks that parts of the sections in the Eniwetok and Bikini drill holes can be assigned to this stage. He may be right, but the evidence is very slender and is susceptible to more than one explanation.

Assemblages of *Tg* larger foraminifera have not so far been recorded outside the Pacific Islands.

### The *Tg*/*Th* boundary

The only continuous carbonate sequences thought to include this boundary were described from the Bikini and Eniwetok drill holes (Cole 1954, 1958). Its position cannot, however, be recognized from the larger foraminifera which by this time had declined in variety and importance.

### Tertiary *h*

DIAGNOSTIC FAUNA : as for *Tg* with the addition of *Borelis schlumbergeri* and perhaps *B. pulchrus*.\*

There are no well-described sections through strata assigned to this stage and the faunas are poorly known. Leupold & van der Vlerk (1931) regarded *Th* as equivalent to Pliocene but were unable to distinguish its faunas from those of *Tg*.

In favourable facies, Tertiary *h* sediments can, perhaps, be distinguished from younger rocks by the presence in the latter of *Calcarina spengleri* and *Baculogypsina sphaerulata* (see Todd 1960).

\* See Postscript p. 128.



## VI. NOTES ON THE MARKER FORAMINIFERA

- Genera and species are arranged in alphabetical order throughout this section. The position of each genus and/or species on the range chart is indicated on pp. 129–131.
- Actinosiphon punjabensis* (Davies).  $Ta_1$ . Known from Pakistan, Dhak Pass Beds, Khairabad Limestone, Patala Shales (Davies & Pinfold 1937) and Borneo. The genus is widely distributed, having been described originally from America.
- Aktinocyclus*.  $Ta_3$ – $Tb$ . Numerous records, but the species are of uncertain stratigraphical value. Possibly only a variant of *Discocyclus*. The genus ranges down into the Lower Eocene of Europe (Banner *et al.* 1967) and may yet prove to have a similar range in S.W. Asia.
- Alveolinella*.  $Tf$ -Recent. This genus may be represented by one valid species only, *A. quoyi*, which probably evolved from *Flosculinella bontangensis* early in  $Tf$  times.
- A. fennemai* (Checchia-Rispoli). Lower  $Tf$ . Most of the earliest representatives of *Alveolinella* have either been reported under this name or as *A. borneensis* Tan. However, as neither species has been adequately described or figured it is uncertain how they differ from *A. quoyi*.
- A. quoyi* d'Orbigny. Upper  $Tf$ -Recent. Confined to the Indo-Pacific region. Probably evolved after the Indian Ocean lost its connection with the Tethys. Recent specimens vary enormously in size and shape.
- Archaias*.  $Td$ -Recent. (Range elsewhere : M. Eocene-Recent). A long-ranging and taxonomically difficult genus, the species of which need careful revision on the basis of plentiful matrix-free material. It is doubtful if much reliance can be placed on the ranges normally assigned to the nominal species as they are difficult to tell apart, especially in random sections.
- A. operculiniformis* Henson.  $Td$ -Lower  $Te$ . Only known with certainty from the Lower Asmari Limestone (Eames *et al.* 1962). Its exact range within  $Td$  is unknown.
- A. vandervlerki* de Neve. Lower–Upper  $Te$ . Known from Borneo and Saipan (de Neve 1947 ; Cole 1957), but needs to be redescribed and compared with other species, particularly with “*Taberina*” *malabarica*. The foraminifera listed by de Neve as occurring with *A. vandervlerki* suggest a very late  $Te$  or early  $Tf$  age.
- Assilina*.  $Ta_1$ – $Ta_3$ . A widely distributed genus in the Indo-Pacific region. The following species are believed to be short-ranging, at least within the Indian subcontinent.
- A. cancellata* Nuttall.  $Ta_3$ . The largest species so far reported. Believed to be confined to the early Middle Eocene, but as there are few records this species is not shown on Figure 3.
- A. dandotica* Davies.  $Ta_1$ . First described from the Khairabad Limestone and Patala Shales of the Punjab Salt Range (Davies & Pinfold 1937).
- A. exponens* (Sowerby).  $Ta_2$ – $Ta_3$ . Mainly Lower Khirthar but also reported from late Laki beds (upper part of the Ghazij Shales) by Nuttall (1926c : 122).
- A. granulosa* (d'Archiac) (= *A. leymeriei*).  $Ta_2$ . Gill (1953) discussed the stratigraphical distribution of this species, noting that it occurred at all levels in the marine Laki of the Kohat/Potwar Basin. He also demonstrated its relationship to *A. spinosa* Davies which he regarded as a synonym. Nuttall (1926d) suggested



that *A. ranikoti*, *A. granulosa*, *A. exponens* and *A. cancellata* formed an evolutionary lineage in which intermediate forms could be found.

*A. spira* (de Roissy).  $Ta_3$ . Occurs commonly in Pakistan. According to Nuttall (1926d) it is restricted to the upper part of the Middle Khirthar.

Species of *Assilina* are of limited value for dating limestones since oriented sections or matrix-free specimens are usually necessary for the recognition of specific characters.

*Asterocyclina*.  $Ta_3$ – $Tb$ . Very common in  $Tb$ . Ranges of the species largely unknown except in the Pacific Isles where Cole (1958) has reported several from the lower part of the succession in Eniwetok. At least one species, *A. matanzensis* appears to range throughout  $Tb$ . The earliest known occurrence of *Asterocyclina* in Asia is probably that recorded by Samanta (1965) from the Siju Limestone, Assam, but it occurs throughout the Middle and Lower Eocene of Europe (Neumann 1958) and will doubtless eventually prove to have the same range in the Far East.

*Asterorotalia pulchella* (d'Orbigny) gr. (= *A. trispinosa* Thalmann).  $Tg$ –Recent. The prominent spines possessed by all the known species of the genus should render it readily recognizable in sections of limestone. Huang (1964) has reported the ancestral forms of *A. pulchella*, (*A. multispinosa* and *A. subtrispinosa*) from the Upper Miocene of Taiwan. It would be difficult, if not impossible, to distinguish between these three species in random sections, so the range of the group is given here.

*Austrotrillina* ? $Tc$ ,  $Td$ –Lower  $Tf$ . A small benthic genus readily recognizable in random sections of limestone because of its unusual wall structure. Species recently revised by Adams (1968).

*A. asmariensis* Adams. ? $Tc$ ,  $Td$ –Upper  $Te$ . Best known from the Middle East, but random cuts of limestones from the Indo-Pacific have often yielded specimens indistinguishable from this species. First occurrences are in late Lower or early Middle Oligocene limestones of Iran and Iraq (Adams 1968).

*A. howchini* (Schlumberger). Late Upper  $Te$ –Lower  $Tf$ . The most advanced species of the genus. Typically found in Lower  $Tf$  strata over the entire region, and known to have coexisted with *Orbulina universa* through at least the upper part of its range. Transitional forms to *A. striata* occur in the late  $Te$  limestones of Borneo and Saipan. Last known occurrence is in the Pata Limestone of South Australia.

*A. paucialveolata* Grimsdale.  $Td$ . There are few reliable records of this species which was first described from the Shurau Formation, Iraq.

*A. striata* Todd & Post.  $Td$ –Upper  $Te$ . Widespread throughout the Indo-Pacific. Passes into *A. howchini* at high levels in  $Te$ . First known occurrence is in the late  $Td$  part of the Melinau Limestone, Sarawak.

*Baculogypsina sphaerulata* (Parker & Jones). Pleistocene–Recent. A reef dweller (see Cole 1957, Todd 1960, Cole 1963). Indo-Pacific region only.

*Biplanispira*.  $Tb$ . Common in late  $Tb$  limestones in the Pacific Isles (Cole 1954, 57, 58); also found in New Guinea (Crespin 1938), throughout Indonesia and in Burma (Beets 1949). Occurs in the Melinau Limestone, Sarawak (unpublished record). Present evidence suggests that this genus might be absent from early  $Tb$ . It is not known from Pakistan where it was wrongly said to occur by the writer



(1967 ; 200). The ranges of the five nominal species are unknown. This genus is an evolutionary development of *Pellatispira* and may eventually prove to be represented by a single valid species.

*Borelis*. Tb—Recent. Common from Tc times onward in the Indo-Pacific region but apparently no records from Upper Tf—Th. The only authentic Tb record from the region appears to be that of Cole (1957). Further reports may, however, be expected in the future since it also occurs in the Eocene of the Tethyan region (Schweighauser 1952).

*B. melo curdica* Reichel. Lower Tf. Only known from the north-western part of the area (Iraq and Iran. See Thomas 1950 and James & Wynd 1965, Fig. 78, Upper Asmari Limestone and lowest Gach Saran Formation) but very common in the Tethyan region.

*B. melo melo*\* (Fichtel & Moll). ?U.Te—Lower Tf. Occurs in the Upper Asmari Limestone, Gach Saran Formations, and basal (Guri Member) of the Mishan Formation according to Eames *et al.* (1962) and James & Wynd (1965). Also known from the Somali Republic (writer's identification), and Kenya (Eames *et al.* 1962, pl. VIIF) where it occurs in association with *Flosculinella bontangensis*. There are no unequivocal records from the East Indies or the Pacific. Cole (1958) found two specimens in Eniwetok drill hole F1 which he assigned to this species, although he admitted (p. 764) that they could not be identified with certainty. They occurred in cored material along with *Miogypsina thecidaeiformis*, *Miogypsinoides dehaarti*, *Flosculinella globulosa* and *Gypsina marianensis*, i.e. a typical late Upper Te assemblage, and slightly older than the beds in which *B. melo melo* normally occurs in the Mediterranean region.

*B. pulchrus* (d'Orbigny). Pleistocene to Recent on published evidence, but perhaps ranging down into the Miocene where it may grade into *B. melo*.

*B. pygmaeus*\* Hanzawa. Tb—Upper Te (most common in Td and Lower Te). Cole (1957) figured a specimen from the Upper Eocene of Saipan. This record is almost unique, the only other from Tb strata in the Indo-Pacific being that of Caudri (1934) who reported *N. cf. pygmaea* from probable Tb rocks of West Soemba. Henrici's (1934) records from the Lower Eocene of Timor are probably all incorrect since his illustration (pl. 3, fig. 1) is clearly of *Fasciolites* s.s. and not of *Borelis*. Adams (1965) illustrated this species from the Tc part of the Melinau Limestone, Sarawak. There are many Lower—Upper Te records (e.g. Cole 1957).

*B. schlumbergeri*\* (Reichel). Tg—Recent. There are two doubtful records from Bikini drill hole 2A (Cole 1954 and Todd & Post 1954). It has been reported from the Tg part of cores from Eniwetok Atoll (Cole 1958). This species may be gradational to *B. pulchra* as believed by Hofker (1952) but the evidence for this is as yet inadequate. All the other described post-Eocene species (e.g. *B. parvulus*, *B. primitivus*, *B. philippinensis*) except *B. inflata* (Adams), which is known only from Tc, occur within Te—probably all within Lower Te—but their relative positions and ranges are unknown.

*Boreloides eniwetokensis* Cole, Tb. A rather striking species, so far known only from Eniwetok Atoll but almost certain to be found elsewhere in the future. Other

\* See Postscript p. 128.



records of the genus are all from the Americas, as indicated by Hanzawa (1962).

*Bullalveolina bulloides* (d'Orbigny) emend. Reichel. Td. Only reported from the Asmari Limestone (James & Wynd 1965) and never figured or described.

*Calcarina spengleri* (Linné). Pleistocene–Recent. A reef dweller restricted to the Indo-Pacific region. (See Cole 1957, 1963, and Todd 1960.)

*Chapmanina*. Tb. Known from East Africa and Iran (e.g. Eames *et al.* 1962, James & Wynd 1965) and several times reported from Indonesia but never figured or described. Records of species from Borneo checked by the writer have proved to be erroneous. It is possible that this essentially Tethyan genus, the earliest record of which is from the Middle Eocene (= Ta<sub>3</sub>), did not reach the Far East. Schweighauser (1953) reported it from the Lower Eocene of Italy.

*Coskinolina*. Lower Cretaceous–Tb. Most species difficult to recognize in random sections. A few Tertiary forms may be potentially valuable as stratigraphical markers.

*C. rotaliformis* Cole. Tb. Described (1958) from late Tb beds, Eniwetok Atoll.

*Cycloclypeus*. Tc–Recent. One of the most studied of all the larger foraminifera but still inadequately known from good stratigraphic sections. The embryonic apparatus shows marked evolutionary changes with time (Tan 1932; Drooger 1955; MacGillavry 1962). Specific differences are very arbitrary and often difficult to maintain. Commonly occurring species are :

*C. carpenteri* Brady (including *C. guembelianus* Brady). Upper Tf–Recent. Reliable Tf records are few, but van der Vlerk (1961) reported it from late Tf beds in Java together with the holotype of *Lepidocyclina radiata*, and Cole (1963) reported it from the upper part of the Alifan Limestone of Guam.

*C. eidae* Tan. Lower Te–Tf. Evolved from the Tc/d *C. koolhoveni*/*oppenoorthi* group. Although there are numerous records from the area, the exact level of the first appearance is unknown. It has not been found in the lowest Te beds of the Melinau Limestone. Tan (1932) and Drooger (1955 : 416) have reported it from Lowest Tf.

*C. indopacificus* Tan. ?Upper Te, Lower–Upper Tf, ?Tg. A species frequently reported from Lower Tf (e.g. Caudri 1932 : 173). Exact range uncertain. Cole (1957) tentatively assigned a specimen from the Tagpochau Limestone of Saipan to this species. At the upper end of its range it grades into *C. postindopacificus* and *C. carpenteri*. Caudri (1932 : 176) reported it from beds said to be younger than Tertiary f.

*C. koolhoveni* Tan. Tc. Originally described (1932) from the Lower Oligocene of Java and not subsequently reported elsewhere in the Far East. It is the most primitive cycloclypeid and quite easily recognizable. Its exact range is unknown but it must grade into *C. oppenoorthi* at or about the Tc/d boundary.

*C. oppenoorthi* Tan. Td–?basal Lower Te. Believed to be a marker for Td but must grade downwards into *C. koolhoveni* and upwards into *C. eidae*. The only verifiable records appear to be those of Tan (1932). The ?Te record is from Tjiapoes, Bantam, Java (see Tan, table V).

*C. posteidae* Tan. Upper Te–Lower Tf. Common in Lower Tf. Level of first



- appearance unknown, but Cole (1957) figured a good specimen from an unknown horizon in the Upper Te limestones of Saipan.
- C. postindopacificus* Tan. Not distinguished here from *C. carpenteri* and not, therefore, on the chart.
- C. (Katacycloclypeus)*. ?Te<sub>5</sub>–Lower Tf. This subgenus contains several nominal species which, with the possible exception of *C. (K) annulatus*, are believed to be restricted to Lower Tf.
- C. (K.) annulatus* Martin. ?Upper Te–Lower Tf. Mainly Lower Tf, but also reported (not figured) from the Djonggrangan beds of probable Upper Te age in central Java (van Bemmelen 1949). At the upper end of its range it has sometimes been recorded (e.g., Cole 1945) in association with *Lepidocyclina rutteni*.
- C. (Radiocycloclypeus) radiatus* Tan (= *C. stellatus* Tan). Lower–Upper Tf.
- C. radiatus* is the pillared form of *C. stellatus*. Tan gave the range of *R. stellatus* as Burdigalian–Vindobonian. The difference between *C. radiatus/stellatus* and *C. carpenteri/guembelianus* is merely one of shape (Tan 1932 : 92) and is of no known biological significance.
- Dictyoconoides*. Ta<sub>1</sub>–Ta<sub>3</sub>. A rather striking genus so far known only from the western part of the region (Africa and Pakistan). This apparent geographical restriction may, however, be due to the paucity of information on Lower and Middle Eocene carbonate sediments in south-east Asia.
- D. flemingi* Davies. Ta<sub>1</sub>. Range based on information given by Davies & Pinfold (1937) ; known from the Punjab Salt Range and Tibet.
- D. cooki* (Carter). Ta<sub>2–3</sub>. Numerous records from the Middle Eocene. Gill (1949) showed *D. cooki* to be a senior synonym of *D. kohaticus* Davies and gave its range as Upper Laki (Ta<sub>2</sub>) through the Middle Khirthar. Samanta (1965) reported it from the lower part of the Siju Limestone.
- Dictyoconus*. Lower Cretaceous–Tc. Species difficult to separate in random sections of limestones. Most Palaeogene forms occur in the Lower and Middle Eocene.
- D. melinauensis* Adams. Tc. A structurally simple form known only from the Melinau and Bukit Sarang limestones in Sarawak.
- Discocyclina*. Ta<sub>1</sub>–Tb. A widespread genus represented by numerous nominal species, the final extinction of which is usually taken to mark the end of the Eocene in the Indo-Pacific region. The earliest representatives are apparently all rather small, the largest species occurring in the Middle Eocene and early Upper Eocene. Samanta (1969) has reviewed the Indian species, and these are now much better known than those from the East Indies. A few of the more important forms are mentioned below.
- D. archiaci* (Schlumberger). Tb. Published records suggest that this is a very long-ranging species but the Palaeocene to early Eocene reports from the Indian area are now thought to be incorrect (Samanta 1965, 1969).
- D. dispansa* (Sowerby). Ta<sub>3</sub>–Tb. Believed to be restricted to the Middle and Upper Eocene (Sen Gupta 1963 and Samanta 1965). One of the earliest records is certainly that of Nuttall (1926c).
- D. javana* (Verbeek). Ta<sub>3</sub>–early Tb. Middle to Upper Eocene in the Indian region (Samanta 1965) ; also occurring in Tb (base of the Bukit Besungai limestone)



Sarawak (Adams 1960: specimens deposited in the B.M. (N.H.), register number P 45151).

- D. omphalus* (Fritsch).  $Ta_3$ - $Tb$ . Very widespread. Mainly  $Tb$  but also occurring in the late Middle Eocene ( $Ta_3$ ) of India according to Samanta (1969).
- D. ranikotensis* Davies.  $Ta_{1-2}$ . One of the earliest species, and not so far known outside West Pakistan where it occurs in the highest Ranikot and lowest Laki beds of the Salt Range.
- D. sella* (d'Archiac). ? $Ta_3$ - $Tb$ . Upper Eocene only in the Indian region according to Samanta (1969), but also frequently reported from the Middle Eocene of the Tethyan region.
- D. sowerbyi* Nuttall.  $Ta_3$ - $Tb$ . Middle to Upper Eocene in the Indian region (Samanta 1965, 1969), and reported from  $Ta_3$  beds in Java (van Bemmelen 1949: 105).
- D. undulata* Nuttall.  $Ta_3$ . Apparently restricted to the Middle Eocene in the Indian region (Samanta 1969). Nuttall (1926c) reported it from the lower part of the Middle Khirthar, and this record has been accepted by later authors.
- Fabiania*.  $Ta_3$ - $Tb$ . The first known appearance in the region is in the Prang Stage sediments of Assam, Wilson & Metre (1953). Its last known occurrence is at the top of the  $Tb$  part of Melinau limestone, Sarawak. *F. saipanensis* Cole is the commonly reported  $Tb$  species in the Indo-Pacific.
- Fasciolites*. (= *Alveolina*).  $Ta_1$ - $Ta_3$ . A distinctive genus containing many nominal Indo-Pacific species all of which are in need of revision. *F. vredenburghi* Davies seems to be the first species known from the region. It occurs in the Khairabad Limestones and Patala Shales of the Salt Range. Hottinger (in press) has recognized *F. cucumiformis* in beds of Upper Ranikot age in Sind. The last species to become extinct was probably *F. elliptica* var. *nuttalli* Davies (Kohat Shales and other Middle Eocene horizons, e.g. the lower part of the Siju Limestone, Assam). Commonly reported species are: *F. elliptica* Sowerby—possibly restricted to the Middle Eocene and considered by Eames (1952) to be a synonym of *F. ovoidea*—*F. globosa* (Leymerie), *F. (Glomalveolina) lepidula* (Schwager), *F. oblonga* (d'Orbigny), *F. ovoidea* (d'Orbigny), *F. subpyrenaica* (Leymerie), *F. timorensis* (Verbeek) and *F. wichmanni* Rutten. *F. wichmanni* commonly occurs with *Lacazinella*, *Assilina* and/or *Nummulites javanus*, an association which strongly suggests a late  $Ta_3$  age.

Bakx (1932) discussed the ranges of the various species of *Fasciolites* and *Nealveolina* in the Indo-Pacific region, and so far as the former is concerned there is little that can be added today. However, the ranges he quoted for *F. javanus* and *F. wichmanni* were certainly incorrect. Neither species is known from  $Tb$  or  $Tc$ .

- Flosculinella*. Upper  $Te$ -Lower  $Tf$ . A widespread and short-ranged genus of great stratigraphical value.
- F. bontangensis* (Rutten). ?Upper  $Te$ -Lower  $Tf$ . Believed to be restricted to Lower  $Tf$  and to have evolved from *F. globulosa*. One of the earliest appearances of the species is in the orbitoidal limestones of Christmas Island (Ludbrook 1965) where



it occurs immediately above beds with an Upper *Te* fauna (Adams & Belford: paper in preparation). Mohler (1947) reported *F. bontangensis-globulosa* in association with *Miogypsinoides dehaarti* and an assemblage of lepidocyclines dated as *Tf*<sub>1</sub>. This material must certainly have come from very close to the *Te/Tf* boundary. *F. bontangensis* may have been extinct before the end of Lower *Tf*. It is known from East Africa (Eames *et al.* 1962) to the Pacific Islands. *Alveolina cucumoides* Chapman is a junior synonym.

*F. globulosa* (Rutten). Upper *Te* — ?Lower *Tf*. Grades into *F. reicheli* at the lower end of its range as shown by Mohler (1949) and into *F. bontangensis* at the upper end. It is not certain whether the transition to *F. bontangensis* occurs immediately below or just above the *Te/Tf* boundary.

*F. reicheli* Mohler. Upper *Te*. The first appearance of this species marks the base of Upper *Te* in some successions, e.g. the Melinau Limestone (Adams 1965). It grades upwards into *F. globulosa* according to Mohler (1950).

*Gypsina*. Eocene—Recent. A long-ranging genus with only one species of sufficient interest to merit inclusion here.

*G. marianensis* Hanzawa. Upper *Te*. First described from Saipan but subsequently found in beds of the same age in Eniwetok, Guam and Christmas Island.

*Halkyardia*. *Ta*<sub>3</sub>—Lower *Te*. Numerous records from the whole area. The earliest verifiable occurrence seems to be *H. minima* var. *indica* from the Lutetian (*Ta*<sub>3</sub>) of Cutch (Tewari 1956). The writer (1967) noted that the genus is known from several Lower *Te* limestones in Borneo.

*Heterostegina*. *Ta*<sub>1</sub>—Recent. A very long-ranging genus. It is doubtful if any of the Indo-Pacific Eocene and early Oligocene species are sufficiently well known or diagnostic to be of stratigraphical value, although names such as *H. ruida*, *H. reticulata* appear constantly in the literature. The following are of proven stratigraphical value:

*H. bantamensis* Tan. *Tc*. This species differs from *H. praecursor* Tan in the presence of an umbonal pillar (Tan 1932). Both were originally described from the Lower Oligocene of Java and are believed to be ancestral to *Cycloclypeus*.

*H. borneensis* van der Vlerk. ?*Td*—Lower *Te*. ?Upper *Te*. Very widespread in Lower *Te*. Although Rickwood (1955) and Visser & Hermes (1962) have reported this species from *Tc/d* and *Td* beds respectively in New Guinea (no figures or descriptions given), evidence from the Melinau limestone, Sarawak, suggests that it does not extend down to the base of *Te*. It does, however, appear before *Spiroclypeus* in this particular sequence. Leupold and van der Vlerk (1931) recognized that *H. borneensis* appeared before *Spiroclypeus* in *Te*, when they stated (p. 626) that within the Tidoengsche Landen of eastern Borneo “in the deepest horizons of stage *e*”, they were referring to the Mesaloi marls (about 1,000 metres thick), “no real *Spiroclypeus* is found, although strongly evolved heterosteginae (*Heterostegina borneensis*) do occur”. They regarded *H. borneensis* as a marker for *Te*<sub>1</sub> although they had not at that time examined faunas from a continuous *Td*—*Te* succession. Van der Vlerk's record (1966) of *H. borneensis* in association with *L. (N.) isolepidinoides* from an isolated sample from East Borneo is very interesting since it apparently proves that the ranges of these two species overlap. There are



reports of this species from Upper Te strata (e.g., Rickwood 1955) but they have never been confirmed by figures or descriptions.

*H. saipanensis* Cole. Tb. First described (1953: see Cole & Bridges) from Saipan and subsequently reported from Christmas Island (Ludbrook 1965).

Future work may show that other species of *Heterostegina* have restricted ranges. *Lacazinella*. Ta<sub>3</sub>–Tc.

*Lacazinella reicheli* Bursch. Tb–Tc. So far known only from the Moluccas. Some authors have questioned the reliability of Bursch's Tertiary c determination, but examination of his material in Basle University has confirmed that this species occurs in abundance with well preserved *Nummulites fichteli* in some samples.

*L. wichmanni* (Schlumberger). Ta<sub>3</sub>–Tb. ?Tc. Known only from the New Guinea area (Rutten 1914, 1936, Bursch 1947, Rickwood 1955, Crespín 1962). Exact range within Tb uncertain, but certainly occurring in the lower part since it has been found in Ta<sub>3</sub> beds with *Fasciolites* and *Nummulites javanus* (Rutten 1936, Crespín 1962). The Tc record (Bursch 1947, Table 1) is doubtful.

*Lepidocyclina*. Td–Upper Tf. This genus contains a larger number of nominal species amongst which are many synonyms. There is little reliable information about the morphological variation or ranges of most of the species. *Lepidocyclina* appeared suddenly in the Far East having migrated there from the Americas, probably by way of the Tethys (Adams 1967); the genus finally became extinct in the late Miocene.

Cole (1962) commented that the subgeneric divisions of *Lepidocyclina* cannot properly be maintained. He was almost certainly right in thinking that they have no biological significance. On the other hand, they still have a certain practical value in stratigraphy and may be retained until the age-diagnostic species have been more carefully described and have had their ranges verified.

*Lepidocyclina* (*Eulepidina*). Td–Upper Te. The occurrence of this subgenus in association with *Nummulites* defines Td. It was very abundant throughout Lower Te and became extinct at, or just prior to, the end of Upper Te. A few of the best-known species are listed below, but are not included on the range charts for the reason given above.

*L. (Eulepidina) dilatata* (Michelotti). This species was originally described from the Lower Miocene of Italy, but the name has often been applied uncritically to Oligocene forms in the Far East.

*L. (Eulepidina) ephippioides* Jones & Chapman. First described from the "Miocene" orbitoidal limestones of Christmas Island, and subsequently used as a "sack name" for almost any *Eulepidina*. The types are now known to have come from late Lower Te strata (Adams & Belford: paper in preparation).

*L. (Eulepidina) formosa* Schlumberger. First described from an unknown level in Te strata of Borneo. This species, although well described and illustrated, is unfortunately predated by the rather poorly described *Lepidocyclina* (*E.*) *ephippioides*.

*L. (Eulepidina) papuaensis* Chapman. Originally described from beds of Lower Te age in New Guinea. This name, like *E. dilatata*, has since been applied indiscriminately to Td species.

The subgenus *Eulepidina* is in great need of revision and, in the writer's opinion,



it is not at present possible to distinguish satisfactorily between one nominal species and another.

- Lepidocyclina* (*Nephrolepidina*). Td–Upper Tf. It is not known whether or not this subgenus ranges right down to the base of Td, but it is almost certain that it does not extend to the top of Tf. However, since Tg is normally defined by the absence of *Nephrolepidina*, its occurrence high in Tf has at present to be assumed.
- L. (N.) ferreroi* Provale. ?Late Upper Te–Lower Tf. A readily determinable species largely restricted to Lower Tf. Although there are numerous records (e.g., Caudri 1932, 34, 39) from strata of this age, there is no way of determining which are the oldest and youngest. Tan (1932) listed *N. ferreroi* together with *Eulepidina* and *Cycloclypeus eidae* from Paloe Soreng, Borneo, but this determination cannot be verified as there is no figure or description. Hanzawa (1957, Table 2) reported it from the Tagpochau Limestone, Saipan, in association with *Eulepidina formosa*.
- L. (N.) inflata* Provale (B form is *L. acuta*). Upper Te–Lower Tf. Numerous records. Particularly common in the Upper Te limestones of the Kinabatangan River, Sabah (personal observation).
- L. (N.) isolepidinoides* van der Vlerk. Td–early Lower Te. The most primitive species known from the East Indies, and originally described from beds of Lower Te age. It occurs commonly in Td and early Te strata, and in the latter grades into *N. parva*. Van der Vlerk (1966) reported *N. isolepidinoides* in association with *Heterostegina borneensis* and *Eulepidina*, an assemblage believed by the writer to be indicative of early Lower Te.
- L. (N.) japonica* (Yabe). Upper Te–Lower Tf. Reported from unknown levels in Upper Te by van der Vlerk (1929) and Krijnen (1931), and by numerous authors from Lower Tf beds in the region.
- L. (N.) martini* (Schlumberger). ?Upper Te–Lower Tf, ?Upper Tf. Very common in Lower Tf. Caudri (1939 : 139) has reported, but not figured, this species from an assemblage that can be dated as Upper Te on the presence of *Spiroclypeus* and *Eulepidina*. There are also other records from beds of Upper Te age but the writer has been unable to verify them. The morphological limits of *N. martini* appear to be as uncertain as its stratigraphical range. It may range up into beds of late Tf age.
- L. (N.) parva* Oppenoorth. Td–Lower Te. Upper Te–?Lower Tf. A descendant of *N. isolepidinoides*, common in late Td and Lower Te beds. The upper limit of this species is uncertain as it has been reported from Upper Te strata on Saipan and in cored material of supposed Tf age (see p. 97) from the Bikini drill holes (Cole 1957 & 1954).
- L. (N.) sumatrensis* (Brady) & vars. Lower Te–Lower Tf. This species is most common in Upper Te and Lower Tf sediments. It probably evolved from *N. parva* in late Te times. Caudri (1939) and Cole (1958) have suggested that *N. parva* is a junior synonym of *N. sumatrensis*. However, combining the two species merely obscures the stratigraphical value of the first and last members of the series without providing any compensatory benefits.
- L. (N.) verbeeki* Newton & Holland. Upper Te–?Lower Tf. Commonly encountered in strata of late Upper Te age (e.g., l'Isle de Nias, Douvillé 1912; Saipan, Cole 1957).



Also widely reported from Lower Tf (e.g., Leupold & van der Vlerk 1931 : 632), but these age determinations are difficult to verify. There appears to be no proof that this species ranges up into Lower Tf although it may well do so.

Many other species of *Nephrolepidina* are of potential stratigraphical value, but their ranges cannot at present be determined with sufficient accuracy for them to be worth recording here. *N. angulosa* (Provale), *N. brouweri* Rutten, *N. borneensis* Provale and *N. verrucosa* Scheffen have all been reported from Upper Te and Lower Tf sediments.

In a series of papers extending over the last decade, van der Vlerk (1959-68) has shown that in *Nephrolepidina* the proloculus becomes progressively more highly embraced by the deuterococonch with time. He has expressed this numerically and used it for dating samples containing sufficient specimens for the results to be statistically reliable. The writer recently tested this method on topotype specimens of *N. verbeeki* from Sumatra, on Lower and Upper Te assemblages of *N. cf. parva* from the Kinabatangan River, Borneo, and on a population of *N. howchini* Crespin from the Batesford Limestone, Victoria, Australia. Good results were obtained from the Sumatran and Australian samples, each of which contained only one species, but the results from the Bornean samples, which contained more than one species, were contradictory and meaningless. It seems that the method requires further refinement before it can be applied generally.

*Lepidocyclina* (*Tribliolepidina*). Tf. This subgenus comprises only a few species, the most important of which are:

*L. (T.) orientalis* van der Vlerk. Lower Tf-Upper Tf. First described from the Njalindung beds of Java (late Lower Tf or early Upper Tf) and subsequently reported from Upper Tf beds elsewhere. Certain age determinations based solely on the occurrence of this species may be incorrect, e.g., Cole (1954 & 58) since, as stated earlier, it is likely that Upper Tf is not represented in the Bikini and Eniwetok drill holes. Cole (1954) believes *L. talahabensis* van der Vlerk to be a junior synonym. The types of both species come from the same locality.

*L. (T.) radiata* Martin. Lower Tf-Upper Tf. According to van der Vlerk (1961) the types come from the late Tf of Java. This age determination was, however, based partly on the evolutionary stage reached by the embryonic apparatus and cannot, therefore, be accepted without reservation. There is as yet no objective stratigraphical or palaeontological evidence to prove a late Tf ( $Tf_3$ ) age for the types. Cole (1960) placed eight species in synonymy with *L. radiata* and even if only three of these (*L. suvaensis*, *L. fijiensis* & *L. oneatensis*) are accepted as synonyms, the effect is to increase the range of *L. radiata* to the whole of Tf.

*L. (T.) rutteni* van der Vlerk. Lower-Upper Tf. First reported from the Tji Lanang beds, uppermost Tf, of Java. Also found occasionally in Lower Tf assemblages as indicated by Caudri (1932). Level of extinction unknown.

*L. (T.) talahabensis* van der Vlerk. Late Lower-Upper Tf. Originally reported from Java, and subsequently from the Barito Basin, Borneo, in beds said to be  $Tf_{2-3}$  in age (van der Vlerk 1966). However, since the dating of these beds depends on the presence of this species, their age cannot be verified. (See *L. (T.) orientalis*.)



*Lepidocyclina*. Td-Tf. The microspheric forms of most species are commonly referred to simply as *Lepidocyclina*, since it is difficult to know which subgenus and species each represents.

*L. acuta* (Rutten) Upper Te-Lower Tf. Probably the megalospheric form of *N. inflata* Provale, although the two are not always found together.

*L. flexuosa* Rutten. Upper Te-Lower Tf. Exact levels of first and last occurrences unknown, but very common in both stages.

*Linderina*. Ta<sub>2</sub>-Tb. Widespread and common. Silvestri (1942) reported it from the Lower Eocene of Somaliland. Elsewhere in the region, the first known appearances are in the Prang Stage sediments of Assam (Wilson & Metre 1953), in limestones from Rajasthan, India (Singh 1953) and in the Kohat Shales, Pakistan (Eames 1952). This genus also occurs in association with *Pellatispira* in the Upper Chocolate Clays of the Sulaiman Range, Pakistan. These specimens have never been described, but are deposited in the British Museum (Natural History), register numbers P 48503-7 (Siddiqui collection). Records of *Linderina* from Lower Te limestones of Borneo are either due to errors in determination of *Miogypsinoides* and/or *Planorbulinella* (e.g., Newton & Holland 1899), or else represent reworked Eocene specimens as at Keramit (Adams & Wilford : in press).

*Lockhartia*. Ta<sub>1</sub>-Ta<sub>3</sub>. So far only described from the western part of the region. First occurrence appears to be in the Dhak Pass Beds, Pakistan (Davies & Pinfold 1937). Nagappa's record (1959, Table 6 & Chart 1) from the Upper Eocene of Pakistan is believed to be incorrect since he quotes as his authority Eames (1952) who makes no mention of this genus from the Upper Chharat beds of Kohat. These beds are, in any case, regarded as Middle Eocene by most authors. Silvestri (1942) described *L. alveolata* from the Middle Eocene of Somaliland.

*Marginopora vertebralis* Blainville. Upper Te-Recent. Very common during and after Upper Tf times. Level of the first appearance difficult to ascertain as the genus can be confused with *Sorites* in random sections of limestone. Cole (1957, pl. 103) figured two specimens from the Tagpochau Limestone (Te) of Saipan, but in the writer's opinion they could have been assigned to *Sorites*. On the other hand, Hanzawa (1957, pl. 6, fig. 7) figured a good vertical section from the Upper Te part of the Tagpochau Limestone on Tinian Island which is also part of the Mariana group. This specimen occurred in association with *Miogypsina* spp. and *Gypsina marianensis*. *M. vertebralis* has often been reported from Lower Tf limestones, e.g., the Tulki and Trealla limestones of Australia (Crespin 1955).

*Meandropsina anahensis* Henson. Upper Te-mid.Lower Tf. Known from the Middle and Upper Asmari Limestone and from the lower part of the Gach Saran Formation.

*Miogypsina*. Upper Te-Lower Tf. ?Upper Tf. This genus includes a considerable number of nominal species, the ranges of which are uncertain. It appeared in the Indo-Pacific region at the beginning of Upper Te times and was probably extinct by Upper Tf. Unfortunately, it is not possible even to determine the youngest record with any degree of confidence. Drooger (1963) indicated that it is *M. antillea* (= *M. tuberosa* in the East Indies), but the evidence for the age of the type specimens is very poor. Caudri (1932) reported "*tuberosa*" from Javanese



assemblages including *Lepidocyclina rutteni*, *Cycloclypeus annulatus*, *C. neglectus* var. *indopacifica* and other miogypsinids, an association suggesting that the beds were not younger than Lower Tf. On the other hand, Banner *et al.* (1967) gave the last record as *M. subtilis* (= *M. cushmani* var. *subtilis*) from the Bentang Series of Java, which they claim is Middle Miocene in age. Van Bemmelen (1949) said that this Series was "Young Miocene" in age. Unfortunately, there is no way of checking this determination. Clarke & Blow (1969 : 88, 89) quoted *M. indonesiensis* Tan as the last known representative of the genus in the Far East. They claim that it occurs in Tf<sub>3</sub>, but the weight of stratigraphical evidence strongly suggests a Tf<sub>1-2</sub> age. The youngest record which the present writer regards as acceptable is of specimens from the Njalindung beds of Java (late Lower or early Upper Tf).

There appears to be no reliable evidence to support the belief that *Miogypsina* occurs in Upper Tf, although there are records in the older literature (e.g., *M. epigona* Schubert from the Bismark Archipelago: Schubert 1910 & 1911) of *Miogypsina* occurring in association with *Orbulina* and *Globorotalia menardii*.

*M. thecideaeformis* (Rutten). Upper Te–Lower Tf. This is one of the most commonly reported Upper Te species, along with *M. kotoi* Hanzawa, *M. neodispana* (Jones & Chapman) and *M. irregularis* (Michelotti). *M. excentrica* Tan and *M. polymorpha* (Rutten) certainly occur in Lower Tf as do others that continue up from Te.

*Miogypsinoides* (including *Miogypsinella*). ?Td, Lower Te–Lower Tf. The earliest occurrence is that reported by Tan (1932, no figure or description given) from Java. There are no other Td records. However, since the genus occurs in the Middle Oligocene of the Tethyan region (Drooger 1963) it might well be expected in beds of the same age in the Far East.

*M. bantamensis* Tan\*. Late Lower Te. This species occurs in beds a little older than those with *M. dehaarti* on Christmas Island (Adams & Belford : paper in preparation) and in a deep well on Kita-Daitô-Zima (Hanzawa, 1940).

It appears that *M. bantamensis*, *M. lateralis* Hanzawa and *M. borodinensis* (Hanzawa) all occur at high levels in the Lower Te limestones of Saipan (Hanzawa 1957 & Cole 1957), but the ranges of the individual species are unknown.

*M. complanatus* (Schlumberger) (including *M. ubaghsi* Tan). ?Td, Lower Te. Although the published records are unreliable this is nevertheless the probable range of the species since it agrees well with the range in Europe. The writer has seen this species in late Lower Te beds of Christmas Island and in various Lower Te limestones (e.g., Keramit, exact horizon unknown) in Borneo. Adams (1965) reported it from the Lower Te part of the Melinau limestone, but the older records on which this occurrence was based have since been checked and found to be erroneous.

*M. cupulaeformis* (Zuffardi-Comerci). Upper Te–Lower Tf. Originally described (1929) from beds which can be dated as Upper Te from the associated faunas (*Spiroclypeus*, *Miogypsina*, *Eulepidina* etc.). Although Cole (1954 & 1958) reported this species from the youngest "Tf" limestones of Bikini and Eniwetok, there seems to be no real evidence that these beds are younger than early Tf in age.

\* See Postscript p. 128.



Diagnostic Tf species such as *Alveolinella quoyi*, *Flosculinella bontangensis*, true *Austrotrillina howchini* and *Lepidocyclina rutteni* are all absent. *M. cupulaeformis* was, however, found with diagnostic Lower Tf species in the Bonya Limestone, Guam (Cole 1963). Drooger (1953) and van der Vlerk (1966a) were almost certainly correct in regarding the type specimens of this species as synonymous with *M. dehaarti*, in which case Cole's Tf specimens may require a new name.

*M. dehaarti*\* van der Vlerk. Upper Te. (Also early Lower Tf according to some authorities, e.g. Mohler 1947; Eames *et al.* 1962, but never figured from beds of this age.) The *Lepidocyclina* species associated with Mohler's specimen certainly suggest an early Tf age. Widespread over the region and normally a good marker for Upper Te. See also *M. cupulaeformis*.

The types of *M. dehaarti* came from the island of Larat, Moluccas, and were associated with numerous planktonic foraminifera including *Globigerina binaiensis*, *Globigerinoides quadrilobatus primordius*, *Globoquadrina altispira* and *Globorotalia kugleri* (van der Vlerk 1966a, 1968b), an assemblage clearly indicative of Blow's Zone N4. In the writer's opinion, Zone N4 must straddle the Lower/Upper Te boundary since the *Globigerinoides quadrilobatus* group of planktonic foraminifera had certainly made its appearance in the Far East before *M. dehaarti* evolved.

*Miscellanea.* Ta<sub>1</sub>.

*M. miscella* (d'Archiac & Haime). Ta<sub>1</sub>. Reported by Davies & Pinfold (1937) from the base of the Dhak Pass beds to the top of the Patala Shales, Punjab Salt Range, Pakistan. This species has been reported, but never figured or described, from Palaeocene beds of Indonesia. However, the identification of specimens from the Engkilili Formation, Lupar Valley, Sarawak (see Liechti *et al.* 1960 : 55) has been confirmed by the writer. Bursch's record of *M. miscella* from Tb, Tc and Lower Te beds on Gross Kei can be discounted since his figured specimens could equally well be of *Elphidium* or some closely related genus.

*Nealveolina.* (See *Borelis*.)

*Nummulites* s.s. Ta<sub>1</sub>–Td (Ta–Recent *sensu* Treatise on Invertebrate Paleontology).

This genus includes a large number of nominal species, many of which are of doubtful validity and uncertain stratigraphical value. It is at present impossible to determine the ranges of most Indo-Pacific species accurately and only a few of the most valuable are listed here. Striate species range from Ta<sub>1</sub>–Td and are commonest in Ta<sub>2</sub>–Tb. Reticulate forms are unknown from the region before Tb and are commonest in Tc and Td. Species such as *N. lahiri*, so far known only from Pakistan, are not included on this chart, nor are such long-ranging species as *N. semiglobulus* and *N. mamilla*.

*N. atacicus* Leymerie. Ta<sub>2-3</sub>. Numerous records from Laki and Lower to Middle Khirthar rocks. The paucity of carbonate sediments of the right age probably accounts for the non-discovery of this species in the East Indies.

*N. carteri* d'Archiac & Haime. Ta<sub>3</sub>. Believed to be restricted to the upper part of the Middle Khirthar. Few records (e.g., Nuttall 1926c).

*N. chavannesi* de la Harpe. Tb. Reported from the western part of the region, e.g. Somaliland (Silvestri 1938) and by Samanta (1968b) from the Kopili Formation,

\* See Postscript p. 128.



Garo Hills, Assam. There is also an unpublished record by Bayliss from West Pakistan (see Samanta *op. cit.*).

- N. fabianii* (Prever). Tb. There are as yet very few records of this important marker from the central and eastern parts of the region. However, it is known from the Upper Eocene of East Africa (Azzaroli 1952; Eames *et al.*, 1962) and from Assam (Samanta 1968b). It is known to overlap with *Orbitolites complanatus* in Africa (Azzaroli 1952).
- N. fichteli* Michelotti. Tc–Td. Very widespread and almost certainly derived from the Upper Eocene *N. fabianii*, from which species it can be difficult to distinguish at very low levels in the Oligocene (Adams 1965).
- N. gizehensis* (Forskål). Ta<sub>3</sub>. This well-known species is usually regarded as diagnostic of the Middle Eocene. Samanta (1965) reported it from the upper part of the Siju Limestone, Assam, which he dated as early Upper Eocene (basal Tb), but later (1968a) regarded as transitional from Middle to Upper Eocene.
- N. javanus* Verbeek. Ta<sub>3</sub>–?basal Tb. The commonest large species of *Nummulites* in Indonesia, and believed by some to be synonymous with *N. perforatus*. The megalospheric form has often been recorded as *N. bagelensis* Verbeek. The ?Tb occurrences are at the base of the Bukit Besungai Limestone (Adams & Haak 1962) and the base of the Melinau Limestone, Sarawak (Adams 1965).
- N. millecaput* Boubée. Ta<sub>3</sub>. So far known only from the western end of the region. Davies (1940b) said that this species occurs in the uppermost Lutetian of the Indian region, but Nagappa (1959, Chart 3) extended its range into the Upper Eocene. However, reference to Eames (1952) shows that there is no evidence to support the Upper Eocene part of the range.
- N. nuttalli* Davies (= *Ranikothalia nuttalli*). Ta<sub>1</sub>. Well known from Pakistan. The only verifiable record from Indonesia, that of Van der Vlerk (1929) was disputed by Caudri (1934) who renamed the Bornean species *N. borneensis*. The writer, having sectioned one of Davies' paratypes (P 39407 B.M.N.H.), agrees with Caudri that van der Vlerk's specimens are not the same as those from Pakistan.
- N. pengaronensis* Verbeek. Late Ta<sub>3</sub>–Tc, ?Td. Numerous Tb records. Samanta (1968b) noted that it occurs in the lower part of the Siju Limestone, i.e., Ta<sub>3</sub> in Assam. Van der Vlerk (1929) reported and figured this species from beds of Tc age in Borneo. The Td report is that of Eames *et al.* (1962), whose record was based on a single specimen from a muddy sandstone. The possibility of reworking cannot be discounted in this instance.
- N. thalicus* Davies. Ta<sub>1</sub>. Best known from Pakistan. Unlike Caudri (*op. cit.*), the writer accepts van der Vlerk's identification of this species from Borneo.
- N. vascus* Joly & Leymerie. Tc–Td. This is a commonly reported species from the Middle East where it occurs in strata of Lower and Middle Oligocene age. It is also known from Tanganyika (Eames *et al.* 1962 : 67). There are records of this species in beds of Upper Eocene age in the Mediterranean region, but to the best of the writer's knowledge it has not been found in strata of this age in Indonesia.
- Operculina* (including *Operculinella* & *Operculinoides*). Ta<sub>1</sub>–Recent. The species of this long-ranging genus are, on the whole, difficult to recognize with certainty, particularly in random sections of limestone. However, it is possible that species



such as *O. rectilata* (Cole), Tg of Guam and post-Miocene of Bikini, *O. lucidisutura* Cole and *O. amplicuneata* (Cole) may eventually prove to be of some value.

*O. canalifera* d'Archiac. Ta<sub>1</sub>. According to Davies & Pinfold (1937) this species ranges from the base of the Dhak Pass beds to the top of the Patala Shales in the Punjab Salt Range. Specimens very like it occur in the Bukit Asi Limestone, Baram River, Sarawak.

*O. salsa* Davies (B form is *O. subsalsa* Davies) Ta<sub>1</sub>. Occurs throughout the Ranikot beds of the Punjab Salt Range according to Davies & Pinfold (1937).

*O. sindensis* Davies. (= *Sindulites* Eames 1968) Ta<sub>1</sub>. First reported from the highest Ranikot beds at Thal and subsequently from beds of the same age elsewhere.

*Opertorbitolites*. Ta<sub>1-2</sub>. The common species *O. douvillei* is fairly widespread in beds of Laki age. Gill (1953) reported *Opertorbitolites* sp. (not *O. douvillei*) from the Lower Eocene of the Punjab Salt Range. The writer has seen it in the Ranikot beds of Dunghan Hill, Pakistan, and in Ta<sub>1</sub> limestones in Sarawak.\*

*Orbitolites complanatus* Lamarck. Ta<sub>2</sub>-early Tb. Numerous records from the Lower and Middle Eocene of the region. The first recorded appearance in Asia seems to be from Assam (Wilson & Metre 1953), and the last from the Sirki Shales near Kohat, Pakistan (Eames, 1952). Both records are probably correct although neither is supported by figures or descriptions. It occurs commonly in strata of Middle Eocene age in Indonesia. Azzaroli (1952) has reported it from E. Africa in association with *N. fabianii*, a typical Tb species.

*Orbulina*. ?Late Upper Te. Lower Tf-Recent. The *Orbulina* datum is so important in Tertiary correlation that it cannot be ignored even in a paper devoted essentially to larger foraminifera. Most planktonic foraminifera cannot be determined readily in random thin sections of limestone but this genus, especially when present in abundance, is an exception.

Records from Lower Tf are relatively few and are difficult to verify. Some that are believed to be reliable require confirmation. Crespin (1955) reported *Orbulina* from the Tulki and Trealla limestones of Western Australia. Unfortunately, her specimens appear to have been lost. Ludbrook (1961) found *O. universa* and *O. suturalis* in the Pata Limestone of South Australia in association with *Austrotrillina howchini* and *Marginopora vertebralis*, both of which also occur in the Tulki and Trealla limestones, thus suggesting that Crespin's earlier record was accurate. The writer has observed *Orbulina* in association with *Lepidocyclina* (*Nephrolepidina*) spp., *Alveolinella* sp. and *Cycloclypeus* sp. in three samples from New Guinea. In two of these samples the larger foraminifera could be reworked, but in the third (an isolated sample from the Kaifangi River) the association appears to be natural. Although not mentioned by Cole (1963), *Orbulina* is common in the Bonya Limestone of Guam (samples Fi5, Ih5.4, Ts2; personal observation). It also occurs in

\* Doubt has recently arisen about the age of the Bukit Asi Limestone. There is a possibility that some of the algae and larger foraminifera in this limestone are reworked. The Palaeocene age quoted by Harlan Johnson (1966. Tertiary Red Algae from Borneo. *Bull. Br. Mus. nat. Hist. (Geol.)* **11**, (6), 257-280, pl. 1-6) now requires confirmation.



the upper part of the Alifan Limestone (sample Ig8). Professor Cole has kindly informed the writer that *Orbulina* was found with a typical Tf fauna in material from Station 62, Lau, Fiji. This sample is probably Lower Tf in age.

Van der Vlerk & Wennekers (1929) reported *Orbulina* from an assemblage of typical Upper Te larger foraminifera including: *Spiroclypeus*, *Miogypsinoides dehaarti*, *Miogypsina*, *Lepidocyclina mediocolumnata* etc., from Mendingin am Ogen, South Palembang, Sumatra. This record, although unsupported by a figure or description, cannot be disregarded even though it may have been based on a misidentification of *Praeorbulina*. Hanzawa's records (1957) of *Orbulina* in association with *Spiroclypeus* and *Eulepidina* on Saipan are believed to be incorrect. A study of comparable material (U.S.G.S. collections from Saipan in the Smithsonian Institution) failed to reveal this association except in one sample where *Orbulina* was seen together with small (?reworked) fragments of *Eulepidina*. There are numerous other records of the genus in assemblages that would now be regarded as Upper Te (e.g., Rutten 1914 : 37), but they are unaccompanied by figures and cannot be verified.

*Palaeonummulites incrassatus* (de la Harpe). Tb–Lower Te. According to Eames *et al.* (1962), a valuable marker in the Middle East where it occurs throughout the lower part of the Asmari Limestone (= Td–Lower Te). The same authors also report it from East Africa. The level of its first appearance is difficult to ascertain since there are a number of records of *Nummulites incrassatus* and *N. cf. incrassatus* from the late Middle/Upper Eocene of East Africa and the Middle East (see Silvestri 1942, Bozorgnia 1964 etc.).

*Pellatispira*. Tb. The 16 nominal species and varieties are believed to occur entirely within Tertiary b. Records of species within Ta<sub>3</sub> are thought to be of an ancestral form which the writer has also seen in Borneo. Although the genus is widespread and very common throughout the region, the ranges of the species are not readily determinable from the literature. *P. orbitoidea* has been reported from the Prang Limestone of Assam along with several species of *Assilina* and *Nummulites* (Nagappa 1956). However, it is not clear whether these genera occur together or separately. If separately, the limestone (400–900 feet thick) should be assigned partly to the Middle and partly to the Upper Eocene. It may be significant that in a later paper Nagappa (1959) made no mention of *Pellatispira* in the Prang Stage. In Europe, the range of *Pellatispira* appears to overlap with those of such typically Middle Eocene genera as *Orbitolites* and *Fasciolites* (Schweighauser 1953), and in Somalia there is an overlap of *Pellatispira* (*P. tudensis*) and *N. fabianii* with *Orbitolites* (Azzaroli 1952). Caudri (1934) reported *Pellatispira* sp. from Ta<sub>2</sub> beds in West Soemba, but her figures are unconvincing. Umbgrove (1928), in his review of the Indo-Pacific members of the genus, said that it occurred in a few rocks with *Assilina*. However, to the best of the writer's knowledge there is no reliable published record of *Pellatispira* in the pre-Tb rocks of the region.

*Peneroplis*. ?Ta<sub>1</sub>–Recent. Although the genus is widespread, the only well-known fossil species come from the north-western part of the region. Peneroplids are abundant in "back-reef", miliolid limestone facies in the Middle East and East Africa. Their relative unimportance in the Far East may simply reflect the rarity



of this particular facies in this part of the region. The genus seems to have appeared first in the Palaeocene of East Africa (Banner *et al.* 1967).

Henson (1950) recognized a number of species in strata of Upper Eocene to Middle Miocene age in the Middle East and East Africa. Although he believed that each species has a relatively short range, they appear to overlap and intergrade to such an extent that their reliability as stratigraphical markers is questionable. With one exception, therefore, they are not included on the chart although they are listed below.

*P. dusenburyi* Henson (?Ta<sub>1</sub>–Tb). *P. evolutus* Henson (Lower Te–Lower Tf). *P. farsensis* Henson. Lower Tf. Common in Iraq and Iran where it ranges from the Upper Asmari Limestone into the Fars Formation. *P. glynnjohnsi* Henson (Tb–Td). *P. thomasi* Henson (Td–Upper Te).

*Praerhapydionina delicata* Henson. Tc–Lower Te. Known in Lower Oligocene (Tc) strata from the western part of the region to the East Indies. Also reported from the Middle and Upper Oligocene (Td–Lower Te) and Aquitanian (Upper Te) parts of the Asmari Limestone by Eames *et al.* (1962).

*Sakesaria* Davies. Ta<sub>1–2</sub>. This genus includes several nominal species known from East Africa (Ruggieri 1950), Arabia (Smout 1954, Sander 1962) and Pakistan (Davies & Pinfold 1937). It probably occurs throughout the Upper Palaeocene and is almost certainly present in the Middle Palaeocene; it is unknown above the middle of Ta<sub>2</sub>.

*Saudia*. Ta<sub>1</sub>–Ta<sub>2</sub>. This genus clearly crosses the Ta<sub>1</sub>/Ta<sub>2</sub> boundary, but how far it extends into Ta<sub>2</sub> is unknown. *S. labyrinthica* Grimsdale is supposed to be restricted to beds of Ta<sub>1</sub> age, but so far is known only from the Dunghan Limestone, Pakistan (Khan 1956) and Arabia. However, the validity of the distinction between *S. labyrinthica* and *S. discoidea* Henson (the Ta<sub>2</sub> species) is questionable, and the range of the genus is therefore given here.

*Schlumbergerella floresiana* (Schlumberger). Pleistocene–Recent. Known only from the East Indies (e.g., Flores Island & Timor). Hanzawa (1952) recognized one species and one variety when he erected the genus.

*Somalina* Silvestri. Ta<sub>2–3</sub>. Exact range uncertain; definitely occurs in the Lower and Middle Eocene of Iraq, and in the ?Lower Eocene of Somalia; it has recently been found in the lowest beds (conglomeratic limestone) of the Lower Eocene in the Rhaki-Nala section West Pakistan (Bayliss & Samanta: paper in preparation).

*Spiroclypeus*. ?Ta<sub>3</sub>, Tb–?Td. Lower–Upper Te. No records from Tc or Td in the Indonesia/West Pacific area.

(a) Eocene species. Tb in the East Indies, but Azzaroli (1952) figured a specimen (external view only) from the Middle Eocene of Somalia. This could, of course, be a *Heterostegina*. Schweighauser (1953) has reported *Spiroclypeus* from early Upper Eocene and late Lutetian strata in the Mediterranean region.

*S. albapustula* Cole. Tb. Pacific Isles (Eniwetok) only. Occurs in the lower part of the Tb sequence present in drill hole F1.

*S. vermicularis* Tan. Tb. Widespread throughout the region. Numerous records, e.g. Cole (1957) Adams (1965). Not known with certainty from basal Tb.

(b) Te species. Although previous range charts for the Far East show the



Oligo-Miocene representatives of this genus making their first appearance at the base of Lower *Te*, the evidence for this is very poor. As mentioned earlier (see under *Heterostegina borneensis*), Leupold & van der Vlerk (1931) recognized that *Spiroclypeus* did not extend to the base of Lower *Te* in Borneo, and recent work on the Melinau Limestone, Sarawak, indicates that it is absent from the lowest *Te* beds in the only section known to be continuous from *Td* to *Te*. The only known post-Eocene species in Europe, *S. blanckenhorni* Henson, is believed by some to range down into the Upper Oligocene of Aquitaine (Butt 1966). However, the nummulites occurring with these spiroclypeids could be reworked, in which case the fauna should be assigned to the Lower Miocene. There is one unsubstantiated report (Thomas 1950) of *Spiroclypeus* from the Middle Oligocene part of the Asmari Limestone.

Pieron (1965) recorded *Spiroclypeus* from beds of supposed Chattian age in Italy. However, his dating depends on the evolutionary stage reached by the embryonic apparatus of species of *Eulepidina* and *Miogypsinoides*, and these particular evolutionary hypotheses have still to be tested against faunas over which there is good stratigraphical control.

Certain authorities (e.g. Eames *et al.* 1962) have accepted the occurrence of *Spiroclypeus* as proof of a Miocene (i.e., Aquitanian age) for any post-Eocene beds in which it occurs. However, this practice is just as dangerous as determining the age solely on the evolutionary stage reached by the embryonic apparatus of miogypsinids, since it rests on a stratigraphical assumption that has never been proved.

*Spiroclypeus* has never been proved to occur in natural association with *Nummulites* in the Oligocene of the Indo-Pacific region, although Thomas (1950) said that it was present at the base of the Asmari Limestone in Iran, nor has it been found in beds immediately above those with *Nummulites* except in places where diastems are known to exist. The genus may, therefore, be polyphyletic.

The ranges of the nominal species of *Spiroclypeus* are uncertain\*. Differences between species are rather small and they are not easily determinable in random sections.

"*Taberina*" *malabarica* (Carter). Lower *Tf*. Originally described from the Malabar coast, India, where it occurs in association with *Austrotrillina howchini* (see Adams 1968). The true range of this potentially valuable marker fossil will not be known until the Neogene members of the group to which it belongs (*Archaias* s.l.) have been revised.

*Wilfordia sarawakensis* Adams. *Tb*. A striking species so far reported only from Borneo (Adams 1965), but likely to be recognized elsewhere in the future.

## VII. PROBLEMS AND CONCLUSIONS

### *Outstanding problems*

Perhaps the most important contributions that could be made towards improving Indo-Pacific stratigraphical correlation in the near future, would be the detailed description or redescription of the Palaeocene to Oligocene successions in West

\* See Postscript p. 128.



Pakistan, the successions in Java on which part of Tan's original work on *Cyclo-clypeus* was based, the New Guinea Limestone (see Visser & Hermes 1962) and the Kereruan, Taurian and Ivorian limestones of Papua. The Miocene limestones of Ceylon would repay a faunal study, and the Cape Range limestones of Australia need to be re-examined so that Crespin's results can be amplified and her missing specimens replaced. When these successions, and any others that are known to include stage boundaries, have been thoroughly examined, it should be possible to establish the ranges of the most important species of larger foraminifera with considerable accuracy.

As can be seen from Figure 2, carbonate sediments were very well developed in every Letter Stage up to and including Lower Tf. The absence of Ta<sub>2</sub> limestones in Indonesia is a purely local phenomenon. Upper Tf and Tg limestones are, unfortunately, extremely rare even though a considerable period of time was available for their deposition (approximately 8 million years: i.e., Blow's Zones N12-N18). In the Indian region and throughout Indonesia this period was one of intense tectonic activity which resulted in environments unfavourable for the deposition of limestones. It can only be supposed that associated eustatic changes were responsible for the failure of carbonates to be developed on a large scale on what are now the Pacific Islands.

Larger foraminifera are certainly capable of much greater refinement as zone fossils than is practicable at present. However, this is not likely to be achieved until they have been studied in more detail than hitherto, and from sections of considerable thickness. Evolutionary studies could profitably be undertaken in almost any group when material over which there is adequate stratigraphical control becomes available.

Accurate correlation of the sequence of larger foraminifera with the planktonic zonal scheme is, of course, a most important aim, and one which will undoubtedly be realized in the not too distant future.

### Conclusions

Contrary to the impression given by previous range charts, very few larger foraminifera can be proved to appear or to disappear at stage boundaries. Where changes of this kind seem to occur, it is because the stages themselves are defined in terms of the ranges of particular genera and species, or because the boundaries in the sections so far described, all coincide with disconformities.

The restriction of some important Tertiary species to Pakistan, Africa or the Middle East, is more apparent than real, and usually reflects the absence of appropriate facies elsewhere in the region. There can be no doubt that facies control is also responsible for the relatively short stratigraphical ranges attributed to some species.

Remarkably little is known about stage boundaries or about the faunas immediately adjacent to them. This is reflected in our inability to establish the ranges of most marker species with any great precision. With a few notable exceptions, transition faunas between the Letter Stages are unknown.

The Oligocene/Miocene boundary appears to coincide approximately with the Lower/Upper T<sub>2</sub> boundary which, in turn, is somewhere within Blow's Zone N<sub>4</sub>



(= *kugleri* Zone *pars* of Bolli) and a little above the first appearance of the *Globigerinoides quadrilobatus* group of planktonic foraminifera. The *Orbulina* datum must be roughly coincident with the Upper Te/Tf boundary.

Previous authors have invariably placed Lower Tf in the Lower Miocene. When this is done, practically the whole evolutionary history of "Neogene" (*sensu* Td-Recent) larger foraminifera has to be compressed into the late Oligocene and early Miocene, a period of approximately 13 million years. The following 19 million years then has a very low rate of evolution for the same group. With Lower Tf assigned to the Middle Miocene, as on the present charts, 20 million years are available for the main part of the group's evolutionary history, and the low rate of evolution is confined to the last 12 million years, by which time the majority were already extinct.

It is apparent that the principal value of the Letter Classification is in the recognition and dating of Lower and Middle Tertiary sediments. The late Neogene stages cannot be distinguished satisfactorily on the basis of larger foraminifera and the classification is therefore unsatisfactory for this part of the Tertiary. However, it must be emphasized that European stage names cannot at present be substituted for the Letter Stages, and that a generally acceptable stage terminology for the Tertiary will not be possible until more detailed biostratigraphical work has been done, and the ranges of the larger foraminifera correlated more closely with those of the plankton.

#### POSTSCRIPT

Since this paper went to press an important publication (Cole 1969) on the larger foraminifera from two drill holes on Midway Atoll, has appeared. Apart from extending the geographical ranges of some important Indo-West Pacific species a little farther to the east, Cole's paper contains the following information relevant to the present work :

1. A Tertiary *e* (Upper Te in the writer's opinion) fauna is recorded from a depth of 590–1,126 feet in the Reef hole. It includes *Austrotrillina striata* Todd & Post, *Flosculinella globulosa* Rutten, *Marginopora vertebralis* Blainville, *Miogypsinoides dehaarti* (van der Vlerk) and *Spiroclypeus margaritatus* (Schlumberger).

2. The fauna in the beds between the surface and 590 feet includes *Borelis pulchrus* (d'Orbigny) [called *B. melo* (Fichtel & Moll) by Cole], *Heterostegina suborbicularis* d'Orbigny, *Marginopora vertebralis*, *Sorites marginalis* (Lamarck), and *Sorites orbiculus* (Forskål). This assemblage could be of any age from Middle Miocene to Recent, but the total absence of diagnostic Lower and Upper Tf species suggests that a large part of Miocene time is not represented in these holes.

3. *Marginopora vertebralis* occurs in beds that are certainly dateable as Tertiary *e*, thus confirming that the range quoted in this paper is correct.

Cole attempts to show that all the Miocene species of *Spiroclypeus* in the Pacific region can be assigned to *S. margaritatus*, that *Miogypsinoides bantamensis* Tan and various other "species" are synonyms of *M. dehaarti*, and that *Borelis melo* is a senior synonym of *B. pygmaeus* and *B. schlumbergeri*. While acknowledging that there are too many nominal species in each of these genera, the present writer believes that Cole has stretched the available evidence too far and has obscured the stratigraphical value of some important species.











FIG. 3. The stratigraphical distribution of some important marker foraminifera in the Indo-West Pacific region.

This chart should be used in conjunction with the text (pp. 109-126).

Solid lines = proven range.

Broken lines = range uncertain but valid records occur within these limits.

? = record(s) of doubtful validity.

\* = no records as yet, but the genus known to range down into this stage in the Mediterranean region.

The ranges of genera such as *Cycloclypeus* and *Nummulites* are not shown since they are fully covered by those of the listed species. Genera known to range right through the Tertiary have also been omitted.

#### ALPHABETICAL LIST OF GENERA AND SPECIES

	Position on chart
<i>Actinosiphon punjabensis</i> Davies	6
<i>Aktinocyclus</i> spp.	30
<i>Alveolinella fennemai</i> (Checchia-Rispoli)	106
<i>Alveolinella quoyi</i> d'Orbigny	112
<i>Archaias operculiniformis</i> Henson	68
<i>Archaias vandervlerki</i> de Neve	77
<i>Assilina</i> spp.	16
<i>Assilina dandotica</i> Davies	15
<i>Assilina exponens</i> (Sowerby)	23
<i>Assilina granulosa</i> (d'Archiac)	17
<i>Assilina spira</i> (de Roissy)	35
<i>Asterocyclus</i> spp.	29
<i>Asterorotalia pulchella</i> (d'Orbigny) gr.	114
<i>Austrotrillina asmariensis</i> Adams	63
<i>Austrotrillina howchini</i> (Schlumberger)	93
<i>Austrotrillina paucialveolata</i> Grimsdale	66
<i>Austrotrillina striata</i> Todd & Post	72
<i>Baculogypsina sphaerulata</i> (Parker & Jones)	116
<i>Biplanispira</i> spp.	43
<i>Borelis melo curdica</i> Reichel	102
<i>Borelis melo melo</i> (Fichtel & Moll)	99
<i>Borelis pulchrus</i> (d'Orbigny)	118
<i>Borelis pygmaeus</i> Hanzawa	51
<i>Borelis schlumbergeri</i> (Reichel)	113
<i>Borelloides eniwetokensis</i> Cole	54
<i>Bullalveolina bulloides</i> (d'Orbigny) emend. Reichel	70
<i>Calcarina spengleri</i> (Linné)	115
<i>Chapmanina</i> spp.	42
<i>Coskinolina rotaliformis</i> Cole	55
<i>Cycloclypeus carpenteri</i> Brady	111
<i>Cycloclypeus eidae</i> Tan	76
<i>Cycloclypeus indopacificus</i> Tan	96
<i>Cycloclypeus koolhoveni</i> Tan	62
<i>Cycloclypeus oppenoorthi</i> Tan	65
<i>Cycloclypeus posteidae</i> Tan	92
<i>Cycloclypeus</i> ( <i>Katacycloclypeus</i> ) <i>annulatus</i> Martin	101
<i>Cycloclypeus</i> ( <i>Radiocycloclypeus</i> ) <i>radiatus/stellatus</i> Tan	108
<i>Dictyoconoides flemingi</i> Davies	9

(continued overleaf)



(Caption to Fig. 3 (contd.))

	Position on chart
<i>Dictyoconoides cooki</i> (Carter)	22
<i>Dictyoconus melinauensis</i> Adams	61
<i>Discocyclina archiaci</i> (Schlumberger)	44
<i>Discocyclina dispansa</i> (Sowerby)	25
<i>Discocyclina javana</i> (Verbeek)	33
<i>Discocyclina omphalus</i> (Fritsch)	39
<i>Discocyclina ranikotensis</i> Davies	13
<i>Discocyclina sella</i> (d'Archiac)	40
<i>Discocyclina sowerbyi</i> Nuttall	26
<i>Discocyclina undulata</i> Nuttall	28
<i>Fabiania</i> spp.	32
<i>Fasciolites</i> spp.	7
<i>Flosculinella bontangensis</i> (Rutten)	98
<i>Flosculinella globulosa</i> (Rutten)	84
<i>Flosculinella reicheli</i> Mohler	83
<i>Gypsina marianensis</i> Hanzawa	90
<i>Halkyardia</i> spp.	31
<i>Heterostegina bantamensis</i> Tan	60
<i>Heterostegina borneensis</i> van der Vlerk	75
<i>Heterostegina saipanensis</i> Cole	47
<i>Lacazinella reicheli</i> Bursch	52
<i>Lacazinella wichmanni</i> (Schlumberger)	38
<i>Lepidocyclina</i> ( <i>Eulepidina</i> ) spp.	64
<i>Lepidocyclina</i> ( <i>Nephrolepidina</i> ) spp.	69
<i>Lepidocyclina</i> (N.) <i>ferreroi</i> Provale	100
<i>Lepidocyclina</i> (N.) <i>inflata</i> Provale	87
<i>Lepidocyclina</i> (N.) <i>isolepidinoides</i> van der Vlerk	67
<i>Lepidocyclina</i> (N.) <i>japonica</i> (Yabe)	88
<i>Lepidocyclina</i> (N.) <i>martini</i> (Schlumberger)	95
<i>Lepidocyclina</i> (N.) <i>parva</i> Oppenoorth	71
<i>Lepidocyclina</i> (N.) <i>sumatrensis</i> (Brady) & vars.	79
<i>Lepidocyclina</i> (N.) <i>verbeeki</i> (Newton & Holland)	89
<i>Lepidocyclina</i> ( <i>Tribliolepidina</i> ) <i>orientalis</i> van der Vlerk	109
<i>Lepidocyclina</i> (T.) <i>radiata</i> Martin	105
<i>Lepidocyclina</i> (T.) <i>rutteni</i> van der Vlerk	107
<i>Lepidocyclina flexuosa</i> Rutten	86
<i>Lepidocyclina acuta</i> (Rutten)	87
<i>Lepidocyclina talahabensis</i> van der Vlerk	110
<i>Linderina</i> spp.	21
<i>Lockhartia</i> spp.	4
<i>Marginopora vertebralis</i> Blainville	94
<i>Meandropsina anahensis</i> Henson	81
<i>Miogypsina</i> spp.	80
<i>Miogypsina thecideaformis</i> (Rutten)	85
<i>Miogypsinoides</i> spp.	73
<i>Miogypsinoides bantamensis</i> Tan	78
<i>Miogypsinoides complanatus</i> (Schlumberger)	74
<i>Miogypsinoides cupulaeformis</i> (Zuffardi-Comerci)	91
<i>Miogypsinoides dehaarti</i> van der Vlerk	82
<i>Miscellanaea miscella</i> (d'Archiac & Haime)	1
<i>Nummulites atacicus</i> Leymerie	18
<i>Nummulites carteri</i> d'Archiac & Haime	34



(Caption to Fig. 3 (contd.))

	Position on chart
<i>Nummulites chavannesi</i> de la Harpe	45
<i>Nummulites fabianii</i> (Prever)	46
<i>Nummulites fichteli</i> Michelotti	58
<i>Nummulites gizehensis</i> (Forskål)	27
<i>Nummulites javanus</i> Verbeek	24
<i>Nummulites millecaput</i> Boubée	37
<i>Nummulites nuttalli</i> Davies	11
<i>Nummulites pengaronensis</i> Verbeek	36
<i>Nummulites thalicus</i> Davies	10
<i>Nummulites vascus</i> Joly & Leymerie	57
<i>Operculina canalifera</i> d'Archiac	2
<i>Operculina sindensis</i> Davies	12
<i>Operculina salsa</i> Davies	3
<i>Opertorbitolites</i> spp.	8
<i>Orbitolites complanatus</i> Lamarck	19
<i>Orbulina</i> spp.	97
<i>Palaeonummulites incrassatus</i> (de la Harpe)	53
<i>Pellatispira</i> spp.	41
<i>Peneroplis farsensis</i> Henson	104
<i>Praerhapydionina delicata</i> Henson	59
<i>Sakesaria</i> spp.	5
<i>Saudia</i> spp.	14
<i>Schlumbergerella floresiana</i> (Schlumberger)	117
<i>Somalina</i> spp.	20
<i>Spircolypeus</i> spp.	48
<i>Spircolypeus alba-pustula</i> Cole	50
<i>Spiroclypeus vermicularis</i> Tan	49
<i>Taberina malabarica</i> (Carter)	103
<i>Wilfordia sarawakensis</i> Adams	56

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