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ART. III.—*Problems of Stratigraphic Correlation in the Indo-Pacific Region.*

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Abstract.

The stratigraphic correlation of marine deposits of Jurassic, Cretaceous, and Tertiary age in the Indo-Pacific Region is reviewed. Results of recent bio-stratigraphic studies in the East Indies are compared with the available data on the stratigraphy of New Guinea and of some of the other islands in the south-western Pacific. The significance of larger and smaller foraminifera for the stratigraphic subdivision of the sequence of Indo-Pacific Tertiary deposits into Series and Stages is discussed. Some features of the distribution of sediments and fossils which are believed to indicate important events in the geological history of the Region are enumerated.

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Introduction.

The present paper deals with stratigraphic correlation of Jurassic, Cretaceous, and Tertiary marine deposits in an area between the eastern shores of the Indian Ocean in the west and Fiji in the east and between Borneo and New Guinea in the north and tropical Australia in the south. This is the greater part of what is known in zoogeography as the Indo-Pacific Region. Although important areas of this zoogeographic province are not included in this review (Central Pacific Islands, Philippines, islands in the western Indian Ocean), the use of this convenient name appears to be justified.

Several distinct structural units are recognizable in the Indo-Pacific Region: the opposed stable areas of Sundaland in the north-west and Australia in the south-east, including the Sahul shelf and the southern portion of New Guinea; the belt of moderate young folding around the margins of Sundaland, and the volcanic arcs accompanying this belt; the arc system of the strongly folded Timor-East Celebes geosyncline; two branches of this geosyncline, one in New Guinea and another one, the Westralian geosyncline (Teichert 1939), in North-western Australia. The latter is now structurally incorporated in the stable area while the former has been transformed into a mountain range indicating considerable young folding and faulting. East of New Guinea the folded zone continues in the general direction towards New Caledonia, the New Hebrides, and New Zealand. Beyond this belt there is another stable area, including Fiji and Tonga. The real geological boundary of the Pacific Ocean, based on a dividing line between the areas of andesites and basalts, passes north and east of it. Some authors assume the existence of a largely submerged extension of the Australian stable area, the Melanesian continent, between this boundary and Northern New Guinea.

The great advances made in recent years in the stratigraphy and palaeontology of key areas in the Indo-Pacific Region, connected with the names, among many others, of W. L. F. Nuttall, L. F. Spath, Oostingh, Tan, Umbgrove and van der Vlerk, F. Chapman and Miss I. Crespin, convinced the author that the time for a critical stratigraphic review of the whole region had arrived and that this work could be expected to stimulate further discussion of one of the most fascinating problems of regional geological history.

The present review is not a complete discussion of Indo-Pacific post-Triassic stratigraphy. Its scope is limited to marine sediments because of the uncertainty of age and relations of most of the volcanic rocks of the region, and the comparative insignificance of other non-marine deposits outside Australia. It deals with problems of correlation without presenting detailed descriptions of stratigraphic sequences. For details the reader is referred to stratigraphic summaries covering many parts of the region and quoted in the bibliography.

It is not intended to discuss here the structural theories proposed by numerous authors in explanation of the complex features of the area between Australia, Asia and the Pacific Ocean. Biostratigraphic correlation merely contributes towards the solution of fundamental geological problems by placing the geological events in their proper sequence and relation and by

establishing analogies and differences in the geological history of areas which are to be considered as structural units (stable areas, mobile belts, geosynclines, etc.).

The uncertain and varying definitions of the term "geosyncline" call for some explanation concerning its use in the following discussion. Recently Jean Tercier (1939) compared the latest data on marine sedimentation in the East Indies and elsewhere with Haug's classical and widely accepted views on facies, depth zones, types of deposition, and geosynclines. The present writer, while not entirely in agreement with Tercier's conclusions, is unable to discuss in the limited space available this vast and important problem and has to refer the reader to Tercier's review, particularly to his chapter on "Facies and types of marine sedimentation" (l.c. pp. 87-93), where the five fundamental types, i.e. paralic, epicontinental, geosynclinal, oceanic, and continental, are discussed and defined.

"Present judgment as to methods of stratigraphic palaeontology places weight on the value of evolutionary stages determined in any stock, relies on the testimony of a relatively small number of carefully identified guide fossils that for various reasons may be regarded as most reliable, and endeavours to take full account of ecologic elements in the interpretation of faunal and floral assemblages." (R. C. Moore, *Stratigraphy*, in: *Geol. Soc. Amer. Fiftieth Anniversary Volume*, June 1941, p. 203.)

The American system of stratigraphic terminology, recently formulated by H. G. Schenck and S. W. Muller (1941) shows a much needed way in which confusion in stratigraphy can be avoided. In the Correlation Table accompanying the present paper an attempt is made to distinguish between local terms agreeing in form and definition with the Formations or Groups of this system, and mere descriptive designations. The author does not consider a paper on regional correlation as the proper medium for the creation of new stratigraphic terms which must be based on local stratigraphic data but he ventures to express the hope that in due course all definable lithogenetic units will receive proper and unequivocal formation names. The question whether under certain circumstances some local rock-stratigraphic terms should receive the rank of regional "Stages" replacing the European stage terms or whether in this case an entirely new set of names of independent derivation has to be created, is still open for discussion. The common use, in some parts of the region, of the words "Series" or "Beds" instead of "Formation" is a problem of minor importance. The establishment of "Zones" in post-Jurassic Indo-Pacific sediments is a vital task of future palaeontological research.

ACKNOWLEDGEMENTS.

The author had the opportunity of stimulating discussions concerning problems of Indo-Pacific stratigraphy with Miss I. Crespín, Canberra; Dr. F. W. Whitehouse, Brisbane; and other geologists and palaeontologists in Australia and the East Indies, who also assisted very kindly in obtaining bibliographic references and copies of publications. To all of them the author wishes to express his sincere gratitude and appreciation.

He is further indebted to Mr. W. Baragwanath for arrangements facilitating the re-drawing of the accompanying Correlation Table; and to Mr. W. J. Parr for assistance in the preparation and publication of this paper.

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I. Jurassic and Cretaceous.

1. JURASSIC.

Recent studies of the Mesozoic of the East Indies (Wanner 1931, Umbgrove 1935, 1938) established the existence of a geosyncline extending from Timor through some of the Molucca Islands (Ceram), to East Celebes. The western margin of this geosyncline is formed by the stable area of Sundaland (Malaya, West Borneo, West Celebes) which was only in part affected by intermittent Jurassic and Cretaceous transgressions, and by the zone Sumatra-Java-Soemba, the Mesozoic history of which is only incompletely known but does not suggest geosynclinal conditions. A southern branch, the "Westralian geosyncline" (Teichert 1939), indicates the revival, in Jurassic time, of an important Palaeozoic geosyncline. Faunal relations of the East Indies and Western Australia around the Australian shield with New Caledonia and New Zealand in Jurassic time are well known but the part played by New Guinea in relation to other Mesozoic areas is at present not fully understood.

Stratigraphic correlation in the Jurassic is based on a standard system of ammonite zones which owing to greater climatic uniformity in Jurassic time can be adapted for world-wide use with comparative ease. Stratigraphic terms used in the following discussion are based on the latest revision of this system recently published by S. W. Muller (1941).

THE JURASSIC OF NEW GUINEA.

Owing to peculiarities of facies and preservation of fossils the Jurassic sequence of New Guinea is well known palaeontologically although Jurassic rocks have only rarely been seen *in situ*.

UPPER LIAS is known from Western New Guinea (Etna Bay) where *Coeloceras moermanni* Kruizinga was found (Kruizinga 1926). A Liassic lamellibranch (*Ctenostreon cf. terquemi* Tate) was determined by Bullen Newton (1916, p. 9) from Central New Guinea. Liassic rocks have not been found in situ.

BAJOCIAN is represented by occurrences of *Stephanoceras* (Etheridge 1890, Gerth 1927), including *S. etheridgei* Gerth from Western New Guinea and a similar species described by Etheridge from pebbles found in the Strickland River in Papua. The BATHONIAN of New Guinea is at present not clearly distinguishable.

CALLOVIAN is well represented. Terpstra (1939, p. IV. 2) described micaceous clay-shales in situ, with "*Macrocephalites*", undetermined belemnites, *Homomya* and *Inoceramus* from the Woesi River (Upper Lorentz River basin), where the Jurassic is transgressively overlain by Oligocene. Callovian ammonites from pebbles were described by G. Boehm (1913) from Western New Guinea where they are considered to be derived from known beds outcropping nearby. Some of the ammonites figured by R. Etheridge jun. (1890, pl. 29) from the Strickland River gravels represent Callovian forms. Their nomenclature has been revised by later authors as follows:—

FIG. 1.—"*Stephanoceras* allied to *S. lamellosum*," now *Kamptokephalites etheridgei* Spath (1928, p. 200, pl. 12, fig. 3).

FIG. 2.—"*Stephanoceras* allied to *S. blagdeni*," now *S. aff. etheridgei* Gerth (1927).

FIG. 3.—"*Stephanoceras* allied to *S. lamellosum*," now *Macrocephalites keeuwensis* β G. Boehm, or *M. waageni* Kruizinga non Uhlig (Kruizinga, 1931).

FIG. 4.—"An ammonite allied to *A. lingulatus*."—?

FIG. 5.—"*Stephanoceras* allied to *S. calloviensis*," now *Dolikephalites flexuosus* Spath (1928, p. 210, pl. 12, fig. 4).

Macrocephalites keeuwensis G. Boehm, according to Spath not a single species but a group of more or less related forms, was first described from the Callovian of the Sula Islands and is also known from Western New Guinea and from Sepik River pebbles (Schlüter 1928).

OXFORDIAN was described by Broili (1924) from Western New Guinea where *Belemnopsis gerardi* (Oppel) and *Buchia* ("*Aucella*") *malayomaorica* (Krumbeck) (described as *Pseudomonotis* sp., l.c. pl. 2, figs. 10, 11) occur in dark-grey clay shales. The species have also been seen by the writer in collections from Central New Guinea. Gerth (l.c.) mentions a *Peltoceras* sp. Schlüter (l.c.) found in the Sepik pebbles *Perisphinctes burui* (*taliabuticus*) G. Boehm and *Inoceramus*

galoi G. Boehm, well known species of the Mefa beds of Buru and the Wai Galo beds of the Sula Islands. These beds are placed by Spath in the *cordatus*-zone of the Oxfordian.

No representative species of the uppermost Oxfordian zones and of the Kimmeridgian are known among the ammonites of New Guinea.

TITHONIAN. Schlüter (l.c.) described from the Sepik pebbles the species *Kossmatia desmidoptycha* Uhlig, *Haplophylloceras strigile* (Blanford), and *Blanfordiceras cf. wallichi* (Gray), considering their age as transitional to Cretaceous. They are also known from pebbles derived from Tertiary conglomerates on the Toarim River, Northern New Guinea. According to Spath they represent the uppermost Jurassic.

Jurassic beds of the Sula Islands and New Guinea are generally developed as shales with hard siliceous fossiliferous nodules ("Geodenschiefer"). Facies and affinities of the Jurassic in New Guinea suggest that part of Western and Central New Guinea was a geosynclinal area. It extended possibly into Eastern New Guinea where within the limits of E. R. Stanley's "Astrolabe-Kemp Welch Series" (1923) the present writer found *Pentacrinus sp.* and *Entolium sp.* in slightly altered sandy limestones overlying phyllites at Gailala on the Upper Aibala River. The phyllites overlie highly metamorphic schists (E. R. Stanley's "Owen Stanley Series").

CORRELATION.

Towards the east, only Tithonian ("Portlandian") is known in New Caledonia where the La Foa formation (Piroutet 1917) with *Berriasella cf. novoseelandica* transgressively overlies Triassic. According to Piroutet no earlier Jurassic horizons are known. In New Zealand (Kawhia Harbour, Trechman 1923) the Oxfordian *Buchia-Belemnopsis* assemblage as well as the Tithonian clearly indicate East Indian affinities.

Towards the west the same Jurassic faunal sequence extends into the area of the Spiti shales of the Himalaya (Uhlig 1910). According to Spath (1933, p. 662) this classical section shows a faunal gap apparently corresponding to the break in the New Guinea ammonite fauna:

Spiti shales	{	Chidamu beds.—Tithonian.
		Faunal gap.—Uppermost Oxfordian and Kimmeridgian.
		Belemnite beds.—Middle Oxfordian.
		(Callovia species known from the basal beds.)

Umbgrove (1938, p. 24 f.) although considering our knowledge of New Guinea as inadequate, admits the possibility of this area having formed a geosyncline in Jurassic time after a probably continental period in the Triassic. There are strong indications

of the existence, in Jurassic time, not only of a restricted "Westralian" but of a Circum-Australian geosyncline. It differed from the Timor-East Celebes geosyncline in a less complete record of Jurassic stages, in more consistently terrigenous facies, and partly also in less pronounced post-Jurassic ("Pacific" or "Young Kimmeric") folding.

2. CRETACEOUS.

Wanner (1931) and Umbgrove (1935, 1938) have published summaries of the Mesozoic history of the East Indies to which the reader is referred for more detailed information. Some additional data and new aspects are discussed here.

(a) Sumatra and Borneo.—Lower Valanginian with *Neocomites* is known from Sumatra. Other evidence of Lower Cretaceous is seen in the occurrence of *Orbitolina* in Sumatra, Java, Borneo and Celebes. Umbgrove (1935) has pointed out that in the absence of reliable specific determinations these occurrences cannot be considered as evidence of a "Cenomanian transgression" but indicate only Barremian to Cenomanian age of these generally transgressive rocks.

The Seberuang Formation of Western Borneo is now known (Zeijlmans 1939) to represent a complete sequence of Cretaceous from transgressive Valanginian with *Neocomites* and *Thurmannia* (Bedoengan beds) through *Orbitolina*-bearing rocks to Turonian and Senonian with mollusca and *Globotruncana* (Selangkai beds).

Cenomanian is also known from Western Borneo as sandstones with *Nerinea* and limestones with *Knemoceras pinax* Krause and *Schloenbachia*. In South-east Borneo *Orbitolina*-bearing beds are followed by richly fossiliferous limestones with *Nerinea* and rudistids, of Martapoera. Martin considered these beds as Senonian of Indian (Ariyalur) affinities.

(b) In the "Timor-East Celebes Geosyncline" a transition from highest Jurassic to lowest Cretaceous beds with *Duvalia* (Timor) and *Hibolites subfusiformis* (Misol) probably exists. These beds are followed, according to Wanner (1931), by limestones with "*Globigerina*, *Discorbina*, and *Pseudotextularia*" which are very widely known from the eastern part of the Archipelago. "*Discorbina*" is of course the well-known *Globotruncana* and "*Pseudotextularia*" includes *Gümbelina*. After considerable discussion on the age of these beds, Umbgrove (1938, p. 19) describing the sequence of Misol according to Weber, considered them to represent Barremian to Cenomanian, lying above beds with *Hibolites subfusiformis* (Valanginian-Hauterivian) and below beds with *Inoceramus* and *Durania*, containing Maestrichtian and possible slightly older forms (Wanner 1931, p. 600).

Beds containing *Globotruncana* cannot be as old as Barremian and are possibly not older than Cenomanian. In Mexico, the Gulf Coast region, North Africa, the Alps, Apennines, Greece and the Caucasus detailed micropalaeontological investigations have failed to detect any evidence of pre-Cenomanian *Globotruncana*. The widely quoted *G. canaliculata* Reuss (= *G. linneana* d'Orbigny sp.) however has been described from the Aptian and Albian of the Pyrenees and the Balearic Islands as well as from the Albian Red Chalk of England. It is a common species in the Turonian and Senonian elsewhere. The Seewer beds of the Western Alps which resemble the *Globotruncana* rocks of the East Indies closely, are Turonian, and most of the similar "Couches Rouges" are Senonian. The existence of an unbroken sequence of Cretaceous rocks in the Timor-East Celebes geosyncline can be proved only by detailed micropalaeontological investigations. *Globotruncana stuarti* (Lapparent) found by Tan Sin Hok in rocks from Western New Guinea and determined by Glaessner from the pink limestone first discovered near Port Moresby by J. N. Montgomery (in: B. K. N. Wyllie 1930, vol. 4, pt. 5, p. 34) proves Upper Campanian-Maestrichtian age of the rocks containing it. This species is also clearly recognizable in a photograph of an "inclusion of Cretaceous *Discorbina*-limestone in a Tertiary e-5 limestone" from Celebes, published by van der Vlerk and Dozy (1934, pl. 2, fig. 1).

(c) In North-western Australia Dr. Raggatt (1936) found the Cretaceous commencing with transgressive Upper Albian. The following summary of the sequence in the North-west basin was recently given by C. Teichert (1939, p. 85).—"The lower part of the Cretaceous series consists of about 1,100 feet of greensands, siltstones, and cherts of the Winning series. Belemnite beds, probably not far above the base of the series, are considered to be of Albian age and the early part (Neocomian) of the Lower Cretaceous seems therefore not to be represented. A Lower Cretaceous transgression seems also to have affected the coastal regions much further south at Perth, where I. Crespin reports the finding of foraminifera of that age in strata about 1,650 to 1,750 feet below sea level". The belemnite beds referred to contain according to Whitehouse *Dimitobelus diptychus* (McCoy) and have been named "Cardabia beds" by Glaucert.

Near Darwin, the Point Charles bed contains a fauna of ammonites considered by Whitehouse (1926, p. 279) as typical of the *substuderi*-zone of the Upper Albian, and also the world-wide Upper Albian to Cenomanian *Aucellina gryphaeoides* Sow. "Above the ammonite bed in this region is a whitish rock with impressions of belemnites. . . . It is probably . . . Uppermost Albian or Lower Cenomanian. At Melville Island a bed has yielded *Acanthoceras* and *Inoceramus*. This is obviously

Cenomanian in age, while from the ammonites present it appears more definitely to represent the *baylei*-zone of the Upper Cenomanian." (Whitehouse l.c.). In Sir T. W. Edgworth David's Correlation table of Cretaceous rocks of the Commonwealth (1932, table H) the sequence near Darwin is shown as follows:—

Cenomanian—	{ Melville Island drab-coloured mudstone. Point Charles bed.
Upper Albian—	{ Ferruginous shales of the <i>aequatoriale</i> -zone. Fanny Bay radiolarian shales with belemnites and <i>Ichthyosaurus</i> .

Cenomanian is not definitely known from the North-west basin where the Winning series is followed by chalks, clay shales, *Inoceramus* marls, glauconite sand, and sandy polyzoal limestone (Cardabia series of Raggatt, *non* Glauert). The limestone, probably Maestrichtian according to Spath, contains *Ostrea vesicularis* Lam. and other fossils. From the greensand Spath (1940) described Lower Maestrichtian ammonites including *Kossmaticeras*, *Kitchinites*, *Pachydiscus* aff. *gollevillensis* Grossouvre, etc. The chalks probably correspond at least in part to the Gin Gin chalk several hundred miles further south containing *Uintacrinus* and *Marsupites* (Upper Santonian, according to Spath Santonian and Campanian). The foraminiferal fauna of the North-western Cretaceous determined by Miss Crespin (1938a) appears to suggest Lower Senonian rather than Turonian or Cenomanian age of the chalks and Upper Senonian (Campanian-Maestrichtian) for the higher beds, judging from the occurrence of several world-wide index species.

In Queensland and Central Australia the Roma beds with *Ancyloceras*, *Tropaeum*, *Tetrabelus*, *Peratobelus*, *Maccoyella*, *Pseudavicula* etc. represent, according to Whitehouse (1930, p. 37) Aptian, and the Tambo beds are Upper Albian (*Puzosia*, *Anisoceras*, *Labeceras*, *Aucellina*, *Inoceramus*, etc.).

(d) In New Guinea, as in Australia, no early Cretaceous marine fossils have been discovered, the fauna of the so-called "transition beds" representing, according to Spath, the uppermost zone of the Jurassic. Early reports suggest the occurrence of Cretaceous of Australian affinities (Apt-Albian) in Central New Guinea. Apart from pebbles with Jurassic ammonites mentioned above, Capt. Everill found fossils in situ on the Strickland River, five days' journey by whaleboat above Carrington Junction (Cecilia Junction). C. S. Wilkinson (1888, p. 204) who examined the samples, stated after quoting from Capt. Everill's report: "The high precipices along the river are formed of sandy calcareous strata, of a dark greenish colour, full of fossil shells of Cretaceous age; amongst those collected are *Gryphea*, *Modiola*, *Aviculopecten*, *Protocardium*, *Cidaris*, ammonites, *Inoceramus*, etc. . . . The specimens of fossiliferous greensand rock

collected from the Strickland River lithologically resemble the Cretaceous beds of New South Wales and South Australia." This description makes it quite unlikely that the black siliceous nodules containing Jurassic ammonites which were found in the Strickland River gravels as well as—much later—in the Sepik River are derived from these outcrops. Similarity of fauna and facies of these pebbles suggests a common source, probably in the Strickland-Sepik divide on the north side of the Main Range.

A few years later R. L. Jack and W. H. Rands (1894, p. 93) reported on Cretaceous fossils collected by Sir William MacGregor on the Upper Purari River. MacGregor's route map shows the locality to be near Biroe Village (north of lat. 7°, long. 144° 50'). "The limestones, although containing numerous fossils, have only one which is in a condition to be recognized. This one, however, a belemnite, is of the utmost importance as this cephalopod is most characteristic of the Cretaceous rocks of Europe and Queensland. The genus has not been met with before, so far as I am aware, in New Guinea. I sent the specimen to Mr R. Etheridge, jun., who confirmed my identification. Other Cretaceous fossils have been obtained from the Strickland River. . . . It is evident that the Purari blue limestones must be classed as Cretaceous, and of course, if my surmise that they belong to the same formation is correct, so must the green sandstone." (R. L. Jack, l.c., p. 93, 30th April, 1894). The description of individual samples shows that the limestones contain abundant bivalve shells "and some gastropods like *Anchura*." A. Gibb Maitland (1905, p. 47) used the name "Purari River beds" for this occurrence of Cretaceous.

Sir W. MacGregor's observations and R. L. Jack's determinations received striking confirmation when early in 1940 Dr. S. W. Carey re-visited the locality of the reported Cretaceous on the Upper Purari, and collected samples of rocks and fossils, in connection with geological exploration work carried out in Papua by the Australasian Petroleum Company. The fossils were subsequently examined by the present writer. Among them was a belemnite belonging to the family Dimitobelidae Whitehouse, abundant bivalve shells the most common of which is *Pseudavicula* cf. *papyracea* Etheridge, and the "gastropods like *Anchura*" mentioned by R. L. Jack. The belemnite was sent to Dr. F. W. Whitehouse who determined it as *Tetrabelus* n.sp. This genus is known (Whitehouse 1924, 1930) from the Roma beds (Aptian) of Australia and from the Upper Albian of India. The preservation of the other mollusca in very hard rock makes specific determinations difficult and uncertain. Among others, the following genera are represented in the fauna: *Nucula*, *Trigonia*, *Lima*, *Ostrea*, *Exogyra*, *Mytilus*, *Ptychomya*, *Natica*, *Nerinea*. A small *Lingula* and a tooth of *Lamna* were also found, as well as smaller foraminifera, ostracods, and echinoid remains.

Fossils collected by Patrol Officers of the Papuan Service in the Kerabi Valley north of Mt. Murray in Papua were mentioned by E. R. Stanley (1923, p. 26). They include large ammonites. Stanley states "The majority of these specimens appear to be related to the Upper Cretaceous". They are now being examined by F. W. Whitehouse whose preliminary determinations (*Acanthoceras* sp., *Mantelliceras papuae* nom. nud.) were included in Sir T. W. Edgworth David's correlation chart of the Cretaceous rocks (1932, table H). These determinations prove Cenomanian age of the Kerabi Valley beds.

The Cretaceous of New Guinea includes beds with mollusca resembling those of the Australian Roma and Tambo series (Apt-Albian), Cenomanian with *Acanthoceras*, and Upper Senonian in *Globotruncana*-facies.

(e) The Cretaceous of New Caledonia, although still quite incompletely known, appears to have a similar range and development. According to Piroutet (1917) three "stages" can be distinguished. Each of them is locally found transgressive on Triassic rocks. The lowest is the Dumbéa with *Cardium caledonicum* Munier-Chalmas and *Pellatia garnieri* Munier-Chalmas, followed by andesites. The next higher stage is the Moindou in which three main subdivisions and a large number of fossiliferous horizons are recognizable. Lamellibranchs (*Trigonia*, *Cardium* aff. *dubuchense*, *Exogyra* cf. *couloni* Defr., etc.) and gastropods are almost the only groups of fossils mentioned. A *Trigonia* from the higher part of this stage is said to be comparable with one from the Maryborough beds (Roma) of Queensland but other Australian Cretaceous lamellibranchs may also be present in the Moindou. Judging from the then available data Piroutet did not find any other striking resemblances with Australian species. He believes the Dumbéa and lower Moindou to represent "Eocrétacé" (Barremian?) and the basal upper Moindou to be "Mésocrétacé" (Apt-Albian?). The Upper Moindou may be Cenomanian.

The highest Cretaceous stage in New Caledonia is the St. Vincent containing *Kossmaticeras* cf. *bavani* Stol. (determined by Prof. Kilian), *K. loganianum* Whiteaves, *K. cumshevaense* Whiteaves, *Puzosia* cf. *gaudama* Forbes and a large number of other fossils including an *Inoceramus* described by A. Heim and A. Jeannet (1922). This is clearly a Senonian fauna showing considerable similarities with the Santonian (?) Batley fauna of New Zealand and similar Pacific assemblages (Benson 1928).

In New Zealand according to Finlay and Marwick (1940, p. 83) "the oldest post-Hokonui formation for which a definite Cretaceous age has been established is the Taitai series". It contains the well-known Australian genera *Maccoyella* and *Aucellina* and is Upper Aptian. Albian, Cenomanian, and younger Upper Cretaceous stages are also represented.

CORRELATION.

Lower Cretaceous to Cenomanian sediments west of the Timor-East Celebes geosyncline are mostly rich in *Orbitolina* and *Nerinea* and show Mediterranean affinities. What is known of deposits of the same age from New Guinea and New Caledonia shows epicontinental rather than geosynclinal development and suggests similarities with the fauna of the Cretaceous of Australia and New Zealand) *Dimitobelidae*, aviculid lamellibranchs, no *Orbitolina*), rather than with Borneo and Sumatra. In both areas however relations with the Cretaceous of India are found.

The molluscan fauna of the Senonian shows some characteristic Indo-Pacific or rather Indian and Pacific features, in Borneo as well as in North-western Australia, New Caledonia, and New Guinea. The pelagic smaller foraminifera (*Globotruncana*, *Gümbelina*) become rock-forming for the first time, these rocks from the Timor-East Celebes geosyncline and New Guinea closely resembling rocks of the same age from the Alpine geosyncline in Europe.

II. Tertiary.

1. METHODS OF CORRELATION.

Biostratigraphic correlation of Mesozoic marine deposits is based on zones which are either worldwide or at least useable within the wide limits of a palaeo-zoogeographic province. Correlation of Tertiary deposits is a much more difficult problem on account of climatic differentiation, topographic isolation, and close stratigraphic subdivision of deposits representing a comparatively short time interval. No world-wide scale of fossil-zones based on well-defined ranges of a set of index species exists. A sequence of Tertiary faunal assemblages was long ago established in Europe and it is not surprising to find that workers in other continents first turned to this sequence for guidance by means of direct comparison and correlation. As long as no scale of zones is available, the next higher unit in stratigraphic classification, the stage, must be the basic unit for measuring Tertiary geologic time. The recognition of the European stages in the East Indies proved so difficult that a number of workers gave up and even condemned attempts at inter-continental correlations.

Four different lines of approach to stratigraphic problems in the East Indies, the key area for the Indo-Pacific Tertiary, have been followed.

(a) K. Martin (1919, and earlier publications) was the first to examine critically collections of mollusca and other fossils. He found them so different from the standard European

assemblages that he decided to determine their age by means of Lyell's method, i.e., according to their more remote or closer affinities with the Recent molluscan fauna of the Indo-Pacific Region. This affinity was expressed in percentages of living species for each fauna described. The stratigraphic results of Martin's work were adversely affected by insufficient stratigraphic field evidence on the succession and relations of mollusca-bearing beds and by the much-discussed dangers of the percentage-method. This stratigraphic tool, far from being an exact statistic method for which it was occasionally mistaken, gives generally no more than what even its most determined critics concede, i.e., "a general indication as to early, middle, or late Tertiary age" (Finlay and Marwick 1940, p. 91). In the special conditions of the East Indies this should be read as "early, middle or late *Neogene* age", for which subdivisions the figures are approximately 8-20, 30-45, 50-60 per cent, respectively.

(b) H. Douvillé (1905, and other publications) tried to correlate East Indian Tertiary deposits by comparing assemblages of larger foraminifera with those found in Western Europe. Douvillé's method soon lost favour as a result of confusion then arising over the delimitation of Tertiary stages and the distribution of larger foraminifera in the type areas (F. Sacco, 1905), as well as because of the limited number of species common to both regions and insufficient knowledge of the vast intervening regions of the "Middle East". It appears now, after nearly forty years, that in spite of these difficulties Douvillé's correlations of Aquitanian, Burdigalian and Helvetian with Indo-Pacific formations appear in many cases to be approximately correct.

(c) Van der Vlerk endeavoured to avoid the danger of confusion by dividing and correlating the Tertiaries of the East Indies according to the local sequence of foraminiferal assemblages. In collaboration with Umbgrove (1927) he created local "stages" designated by the letters "a" to "f" (subdivided into "zones" designated by numbers), and based on the distribution of larger foraminifera. The stages "g" and "h", based on other criteria, were added later in order to complete conveniently the subdivision of the Tertiary. The stages were not explicitly referred to type sections but were linked in a general way with the stratigraphic sequence observed by the authors in East Borneo and elsewhere. Later correlation (Leupold and van der Vlerk, 1931) generalized these stages and zones so that they finally included stratigraphic units in which the distinctive foraminifera had not been found.

While not inclined to use European series and stage terms generally, van der Vlerk (1931, p. 207) showed in a chart "the most probable comparison" between European and East Indian subdivisions. Stages "a" and "b" are placed in the Eocene, "c" and "d" in the Oligocene, "e" and part of "f" including the West Progo and Njalindoeng mollusca-bearing beds are considered as Lower Miocene, the rest of the "f-stage" including the Tjilanang and Lower Palembang beds and the "g-stage" are Upper Miocene and the "h-stage" with the Sondé beds is Pliocene.

Gerth (1935) presented additional evidence for the distinction of Eocene, Oligocene and Miocene in Java by comparing occurrences of larger foraminifera with supposedly similar assemblages from Sind, South-west France, and the West Indies.

(d) The collaboration of the palaeontologists Koenigswald (vertebrates), Oostingh (mollusca), and Tan Sin Hok (larger foraminifera) with the field geologists of the Netherlands East Indies Geological Survey placed the study of the Tertiary in the East Indies and indeed throughout the Indo-Pacific Region on a firm base. Koenigswald's work established the sequence of definitely Lower Pliocene, Upper Pliocene, and Pleistocene vertebrate faunas in Java. They were stratigraphically correlated with marine molluscan faunas described by Oostingh, by means of which correlation was extended over larger areas. Tan Sin Hok developed elaborate and important methods of morphological analysis of the structure of larger foraminifera (1932, 1936a, 1939). His latest views on the general subdivision of the Tertiary of the East Indies are here summarized. He finds (1936, 1939a) that the following boundaries are palaeontologically recognizable:—

- (1) Eocene/Oligocene.
- (2) Aquitanian/post-Aquitania (c/f).
- (3) Between two subdivisions of the "Middle Neogene" corresponding to van der Vlerk's "f₁-f₂" and "f₃" respectively.
- (4) Between Middle and Upper Neogene (top of *Lepidocyclina*-bearing sequence, top of "f-stage").

Thus he recognizes:—

Neogene	{	Upper Neogene (formerly g-h).
		Upper Middle Neogene (f ₃).
		Lower Middle Neogene (f ₁ -f ₂).
		Lower Neogene (Aquitanian, "e," included in Miocene).
Palaeogene	{	Oligocene (c-d, distinguishable from Aquitanian only where reticulate nummulites are present).
		Eocene (a-b).

Tan Sin Hok concludes (1939a, p. IV. 100) "The further differentiation of these main divisions can only be successful from the investigation of actual geologic sections, and moreover, if

the several species of larger foraminifera can be defined in a more objective manner. To this purpose the phylogenetic line of investigation will be of great use. In many cases a further subdivision of these stages can at present better be done by the use of local stratigraphic names."

Such names have recently been introduced by Oostingh (1935, 1938, quoted with alterations from Le Roy, 1941, p. 5, p. 110; and modified after Oostingh 1939, p. IV. 141).

Plio-Pleistocene—Bantamian (Bodjong beds).

Pliocene (post-) Sondian (Kali Glagah Upper Pliocene vertebrates).

Pontian) } Cheribonian (Tjidjoelang Lower Pliocene vertebrates).

Miocene { Unnamed stage (e.g., non-marine Genteng beds).

Preangerian (Upper Middle Neogene of Tan).

Rembangian (Lower Middle Neogene of Tan).

These "stages" are based on well-defined molluscan assemblages and guide species many of which were collected from mapped and stratigraphically well known areas in Western and Central Java.

2. CORRELATION OF EOCENE AND OLIGOCENE DEPOSITS.

EOCENE.

Tan Sin Hok has pointed out that definite evidence for age distinction and superposition between beds with and without *Assilina* ("a" and "b" according to van der Vlerk and Umbgrove) is lacking. It appears from recent critical investigations on nummulites (Caudri 1934) that there is no evidence yet for an extensive representation of Lower Eocene in the East Indies. The oldest nummulites correspond, according to Caudri, to those found in India close to the Laki/Kirthar boundary. P. Arni (Ueber die Nummuliten und die Gliederung des Untereocaens. *Eclogae Geol. Helvet.* 32, p. 150, 1939) points out that certain assemblages from isolated outcrops of Eocene in Java contain species occurring also in the Uppermost Lower Eocene of Europe. The upper limit of the Eocene is marked by the sudden disappearance of *Discocyclina*. Occurrences of marine Eocene are scattered through the East Indian Archipelago from the Andaman to the Kei Islands, but the history of the period cannot be traced yet in detail (Umbgrove 1938).

Chapman and Crespin (1935) described nummulites, *Discocyclina*, *Asterocyclina* and *Pellatispira* from the Giralia limestones found by Rudd and Condit in North-western Australia. *Discocyclina* limestones occur there also at Red Bluff and Cape Cuvier (Crespin 1938).

In Western and Central New Guinea Eocene is known as foraminiferal limestones with nummulites, *Alveolina*, *Discocyclina*, *Lacazina*, etc. (Rutten 1927, Crespin 1938b). *Lacazina wichmanni* Schlumberger is definitely Eocene and not Cretaceous

as suspected by Umbgrove (1935, p. 143). Limestone pebbles from the upper Fly River from which Bullen Newton (1918) described foraminifera and Gregory and Trench (1916) corals are not Eocene but Lower Miocene or Upper Oligocene (e-stage). All the corals are described as new species except one which is a new variety of a *Porites*. They can obviously not be used for age determination. The foraminifera are described as *Alveolina wichmanni* Rutten, *Lacazina wichmanni* Schlumberger, *Orthophragmina* sp. *Carpenteria conoides* Rutten, and miliolines with transversely plicated chamber walls "suggesting a relation to *Pentellina saxorum*." The description of the miliolids which cannot be verified from the illustration, suggests *Austrotrillina* Parr (1942) but not the erroneously quoted *Miliola saxorum* which has a normal chamber wall. "*Orthophragmina*" (Bullen Newton l.c. p. 209, pl. 9, fig. 4) refers to an oblique section showing only rectangular median chamberlets and is therefore a *Sorites*. Differences between the supposed *Lacazina* and Schlumberger's species were noticed by Bullen Newton, their alveolinid characters were observed by Miss Crespin (1938b, p. 5), and spiral coiling is indeed plainly shown in fig. 2 (l.c.). The species figured is probably *Nealveolina pygmaea* Hanzawa.

In south-eastern New Guinea Eocene is represented by the Port Moresby beds. Gibb Maitland (1905, p. 47) originally used this name for the entire sedimentary series of the Port Moresby district considering its age as Pliocene. It is now known to range, with at least two breaks, from Upper Cretaceous to Pliocene. The name Port Moresby series was later restricted to the Eocene rocks of Port Moresby consisting of siliceous argillites, cherts, tuffs, and marls with abundant *Globigerina*, *Globorotalia*, *Gümbelina* and radiolaria, with intercalated bands and lenses of limestone containing nummulites, *Pellatispira* and *Discocyclina*. (J. N. Montgomery, F. Chapman, in: Wyllie 1930, vol. 4. List of Fossils quoted by I. Crespin 1938b, p. 4.) The Port Moresby beds are associated with serpentines and gabbro. Slight contact metamorphism is found in palaeogene *Globigerina*-*Globorotalia* limestones. The intrusions are therefore partly Palaeogene or younger. Some of the limestones in Stanley's Astrolabe-Kemp Welch series (Boioro and Mafulu limestones) are probably Palaeogene.

The Eocene of New Caledonia (J. Deprat 1905, Piroutet 1917) shows a similar facies of nummulitic limestones, marls and cherts, associated with an enormous development of serpentine. It is reminiscent of the "serpentine series" and cherts described by Tipper (1911) from the Andaman Islands and of similar rocks of the Arakan Yoma where according to Evans and Sansom (1941) "the main intrusions of serpentized gabbros and peridotites occurred probably in late Cretaceous and Eocene

times." Eocene foraminiferal limestones resting on tuffs and lava flows are known from Eua, Tonga Islands (Hoffmeister 1932).

OLIGOCENE.

In north-western India (Sind) a break corresponding to a major orogenic phase divides the Middle Eocene (Lutetian) Kirthar from the Oligocene Nari. "The lower Nari beds are often crowded with nummulites. These usually belong to the species *N. intermedius* and *N. vascus*. . . . The genus *Lepidocyclina*, Carter's *Orbitolites mantelli*, makes its appearance at a very low horizon in the Lower Nari, often at the very base of the formation. . . . In the Upper Nari the lepidocyclines are also very abundant but are not accompanied by nummulites. . . . All the Nari lepidocyclines appear to belong to one species *L. dilatata*." (Vredenburg 1906, pp. 90f.). The Nari nummulites have since been recognized by Nuttall (1925) as *N. intermedius* and *N. clipeus*. *L. dilatata* was described from the Nari by the same author (1926). As these forms (except *N. clipeus*) are known from Europe, they enabled Nuttall to confirm Vredenburg's correlation of the Nari (as far as it contains *N. intermedius* and *L. dilatata*, Lower Nari according to Vredenburg), with the Stampian (Rupelian) of Europe. "In the Upper Nari, thin discoidal forms predominate, often reaching a diameter of 10 centimeters. This is *L. elephantina* Munier-Chalmas, probably identical with the Burmese form described by Carter as *Orbitolites mantelli* var. *theobaldi*." (Vredenburg, l.c., p. 91). *Lepidocyclina elephantina* was first described from the Chattian (Upper Oligocene) of Isola di Malo in Northern Italy and also from the Aquitanian Schio beds. The Upper Nari was correlated by Vredenburg with the Chattian.

In Burma the Oligocene is more complete. It is subdivided (Glegg 1938, Cotter 1938) into:

Okhmintaung sandstone (Singu molluscan fauna).

Padaung clay (including beds with *L. elephantina*, Yenangyat and Minbu faunas).

Shwezettaw sandstone.

These three "stages" are believed to correspond approximately to the Chattian, Rupelian, and Lattorfian of Europe. Vredenburg correlated the Singu mollusca with the Upper Nari and the equivalents of the Padaung with the Lower Nari. If this is true then *L. elephantina* appears earlier in Burma than elsewhere.

In the East Indies *Camerina intermedia* characterizes the stages "c" and "d." *Eulepidina papuaensis* Chapman appears in beds assigned to stage "d" by Leupold and van der Vlerk (1931). At its type locality, the Bootless Inlet limestone of Port Moresby,

Papua (Chapman 1914, and also in: Wyllie 1930, vol. 4) *E. papuaensis* occurs together with *C. intermedia* so that these beds must be considered as Oligocene. The occurrence of *Spiroclypeus* in the same beds is doubtful. The stratigraphic relation of the Bootless Inlet limestone to the Eocene Port Moresby beds is uncertain. *E. dilatata* has not been found together with nummulites in the East Indies. Douvillé (1905, p. 435) recognized in material from Borneo a distinction between older beds with reticulate nummulites without *Eulepidina* and younger beds (Stampian) with the same nummulites and "*Eulepidina* of the *formosa* group". Leupold and van der Vlerk (1931) and Koolhoven (1933) confirmed this subdivision. Their evidence was not accepted by Tan Sin Hok who however does not deny that the first appearance of the subgenus *Eulepidina* distinguishes the later (Rupelian) from the earlier (Lattorfian) stage.

This raises the question of the representation of the Upper Oligocene (Chattian) in the East Indies, since the Rupelian is generally considered as Middle Oligocene (Vaughan 1924, pp. 712f.). A number of authors let the Aquitanian follow immediately after the Rupelian but this does not seem to be the correct procedure. Although no complete marine sequences are known in the type areas, detailed work elsewhere in Europe has shown that "type" Aquitanian and "type" Chattian do not overlap.

The highest beds with reticulate nummulites are invariably followed in complete sections in the East Indies by beds with *Eulepidina*, *Spiroclypeus*, *Miogypsinoides* and other larger foraminifera. This is stage "e" of van der Vlerk and Umbgrove. The top of this stage was recognized by H. Douvillé, Gerth and Tan as the top of the Aquitanian. The main criterion used for defining the base of stage "e" is the same as that applied by Vredenburg for the distinction between Lower Nari (Rupelian) and Upper Nari (Chattian). Tan (1939a) quotes the following European species from the "e-stage": *Lepidocyclina elephantina* Munier-Chalmas, *L. dilatata* (Michelotti), *L. marginata* Michelotti, *Miogypsinoides complanata* (Schlumberger), *Heterostegina assilinoidea* Blankenhorn. Most of these are known from Upper Oligocene and Lower Miocene (Chattian-Aquitanian). Accordingly, the stage "e" is placed in Chattian and Aquitanian in the European scale (Tan, 1932, Table IV.). Umbgrove has in a number of his publications insisted on the occurrence of important transgressions in a higher horizon of stage "e". Tan, in his critical reviews, does not find sufficiently clear evidence for the recognition of any of van der Vlerk's five "zones" of this stage, and therefore the horizons of transgressions cannot be as accurately fixed within the stage as Umbgrove maintained. Umbgrove's observations agree however in a general way with

Lepper's statement of overlap by the Pyawbwe clay (Aquitanian) and an important unconformity in the uppermost parts of the Oligocene in Burma (quoted by Glegg, 1938).

No molluscan assemblages of "e-age" have been described from the East Indies and direct correlation with Burma is therefore impossible. The Rembang fauna, believed at the time of Vredenburg's work to be Aquitanian, has since been found to be younger and to occur together with typical post-Aquitanian foraminifera.

In the Cape Range limestones of North-western Australia (F. Chapman 1927, I. Crespin 1938) different assemblages of larger foraminifera, mainly *Eulepidina*-species, corresponding to the "e-stage" fauna of the East Indies, have been found. Oligocene is known from New Guinea and New Ireland (Schubert 1911) but has not been reported from the New Hebrides or New Caledonia.

Tan Sin Hok (1939a, p. IV. 100) has warned us that only the presence of genuine reticulate nummulites is stratigraphically important, that their absence may be caused by ecologic conditions and that "in some cases the discrimination of a 'genuine' *Camerina* from *Operculinoides* Hanzawa is very difficult, the latter being *Camerina*-like operculines which also occur in the Indo-Pacific Neogene." Such forms are still creating much confusion in stratigraphy and a revision of the group is urgently needed. It includes *Nummulites niasi* II. Verbeek (= *N. variolaria* Brady 1875, non Sowerby, see R. D. M. Verbeek and R. Fennema, Descr. géol. de Java et Madoura, 1896, vol. 2, p. 1157), *N. makullaensis* Carter (Vredenburg 1906) from the Gaj; *N. doengbroeboesi* Verbeek (Schubert 1911), and possibly other species.

3. CORRELATION OF MIOCENE DEPOSITS CONTAINING LARGER FORAMINIFERA.

In some recent classifications of the Tertiary of the East Indies the use of the term "Miocene" is still avoided. It is admitted that it is at present difficult, if not impossible, to define satisfactorily both the upper and the lower boundaries of this series. It would be easy and perhaps convenient to regard all post-nummulitic *Lepidocyclina*-bearing beds as Miocene but this is not in agreement with the use of the term elsewhere and with its original definition and the typical sequence of rocks covered by it. There is some difference of opinion about the position of the Aquitanian. This, in the writer's opinion, is a purely arbitrary matter to be settled by agreement and not by investigation. The majority of authors now include it in the Miocene. If we accept this view then the lower boundary of

this series in the East Indies is not, at present, biostratigraphically definable. A similar question arises concerning the top of the Miocene. If the Pontian is regarded as uppermost Miocene then all pre-Cheribonian Neogene deposits are Miocene as the Cheribonian includes, by definition, beds containing the earliest post-Pontian fauna of vertebrates. If it is possible, as it appears to be, to distinguish a "g-stage" from the Cheribonian, then this "g-stage" is Miocene under the first of the two alternative delimitations of the Series. If, however, the Pontian is not included in the Miocene then the top of the Miocene is at present not definable.

That the problem is a general one is shown by a statement recently made by G. E. Pilgrim (1940, p. 9):

"The numerous stages or sub-stages into which I have divided the geological succession does not imply that the correlation makes any pretence at being more than approximate, but have been used partly because that is the only means by which I can take account of the large number of American faunas and partly because the system names Miocene, Pliocene and Pleistocene have at present no meaning since they have not been employed by every writer in the same sense."

Notwithstanding these difficulties, a certain part of the East Indian Tertiary sequence is definitely Miocene. This is Tan Sin Hok's "Lower and Upper Middle Neogene", Umbgrove and van der Vlerk's "f-stage", and Oostingh's Rembangian and Preangerian. These latter names appear to be well suited for general use in the Indo-Pacific Region. The Rembangian is tentatively correlated with the Burdigalian and the Preangerian with the Vindobonian (Helvetian-Tortonian) of Europe. Definite evidence, however, is available only for the correlation of the base of the Burdigalian with the base of the Rembangian, the rest being conjectural as long as no further palaeontological evidence is found. In the light of new stratigraphic and micropalaeontological data earlier inter-regional correlations based on mollusca cannot be considered as satisfactory.

Vredenburg (1921a, p. 328) and Martin (1931, p. 7) correlated as follows:—

Younger Miocene	{	Odeng beds—Talar—(Sarmatian-) Pontian.
		Tjilanang beds—Vindobonian.
Older Miocene	{	Njalindoeng beds—Pyalo—U.Gaj—Burdigalian.
		Rembang beds—Kama—L.Gaj—Aquitania.
		Progo beds (not correlated).

Gerth (1929, p. 595) has shown that the foraminiferal fauna of the Rembang beds is definitely post-Aquitania (probably Burdigalian) and that the Progo beds are not greatly different in

age. Van der Vlerk (1924) found that in both Njalindoeng and Tjilang beds only *Tryblholepidina* represents the lepidocyclines and Gerth (l.c., p. 596) concluded that both are "Younger Miocene", younger than the Rembang beds and possibly Vindobonian. According to the same author the Odeng beds are equivalents of the Tjilang beds. The absence of pre-Rembangian molluscan faunas in Java and the incomplete knowledge of Vindobonian molluscan assemblages from India add to the difficulty and uncertainty of molluscan correlation.

The beds containing the Progo and Rembang molluscan faunas and the "f₁₋₂" assemblage of larger foraminifera have been named Rembangian by Oostingh. This stage is characterized, according to Tan Sin Hok (1939a, p. IV. 99) by *Katacycloclypeus*, *Miogypsina bifida* L. Rutten, *M. polymorpha* L. Rutten, *M. musperi* Tan, *Alveolinella* of the *bontangensis*-type (= *Flosculinella*), *Lepidocyclina angulosa* Provale, *L. inflata* Provale, and some other lepidocyclines.

Beds with this foraminiferal fauna are followed in numerous sections examined in East Borneo, Java, Sumatra, and New Guinea by beds containing a younger Miocene molluscan fauna, and instead of the foraminifera mentioned above, a younger assemblage with *Lepidocyclina* (*Tryblholepidina*) *rutteni* van der Vlerk, *L. (T.) orientalis* van der Vlerk, some *Miogypsina*, and *Alveolinella* of the *quoyi* type. They were named "Preanguerien" (here adapted to "Preangerian" according to English spelling) by Oostingh. Tan (l.c.) quotes also *Cyclolepidina* (*recte Multilepidina*) *suvaensis* Whipple as typical for this stage and claims to have found it in Java in the highest *Lepidocyclina*-bearing beds. At its type locality, in the Suva formation of Fiji and in Rembang (Java), the species occurs together with *Katacycloclypeus annulatus*, evidently in beds of Rembangian age.

No distinctive larger foraminifera are found in post-Preangerian beds, reports of *Lepidocyclina* and *Miogypsina* being based either on incorrect assumption of Pliocene age for rocks underlying Pleistocene raised reefs (Tan 1936a, p. IV. 85), on unconfirmed determinations, uncertain stratigraphic data, or derived specimens from older beds.

The correlation of *Lepidocyclina*-bearing rocks throughout the Indo-Pacific Region presents little difficulty. The Cape Range limestones of North-western Australia (Crespin 1938) contain not only "e-stage" assemblages but also a fauna with *Flosculinella bontangensis* and *Austrotrillina* which can be considered as Rembangian. The *Lepidocyclina*-bearing rocks of the north coast of New Guinea were described as "Conglomerat-zone" by Zwierzycki (1921, 1927) and as Aitape series by Nason-Jones (in: Wyllie, 1930). Some part of Zwierzycki's "*Globigerina*-

zone" contains *Lepidocyclina* and is probably Preangerian. *Lepidocyclina*-limestones have repeatedly been reported in situ in the high mountains of the Main Range of New Guinea, including Mt. Carstenz where the "e-stage" fauna occurs, the upper Lorentz River (Terpstra 1939), the upper Digoel River (van Bemmelen 1940) where "e-stage" limestones are followed by a predominantly arenaceous and argillaceous stage tentatively considered as Burdigalian, and the upper Fly River (e-stage, Crespin 1938b). In samples from New Ireland Schubert (1911) found *Lepidocyclina* and *Miogypsina*. A soft *Globigerina*-marl with *Miogypsina lagamiensis* and *M. epigona* was incorrectly assigned by him to the Pliocene. In the Solomon Islands the Orovavi limestone of Bougainville with "e-stage" foraminifera described by Mawson and Chapman (1935) is the oldest known formation. The folded tuffs and foraminiferal marls observed by Guppy (1887) on a number of islands of the Solomon group and considered by him as "Recent", probably represent the younger Tertiary stages. From the New Hebrides (Santo and Malekula) F. Chapman (1905, 1907) described *Lepidocyclina*-limestones which were later named Laleppe formation by Mawson and Chapman (l.c.). Chapman figured foraminifera closely resembling *Lepidocyclina ferrerioi* Provale and *L. inflata* Provale, *L. cf. martini* Schlumberger, as well as *Alveolinella cucumoides* Chapman representing the *bontangensis*-group. The Laleppe formation is evidently Rembangian.

4. CORRELATION OF MIOCENE AND PLIOCENE DEPOSITS NOT CONTAINING DISTINCTIVE LARGER FORAMINIFERA.

THE STAGE "G".

To van der Vlerk's stages "a to f", all characterized by distinctive larger foraminifera, Umbgrove (1929, reprint, p. 5) added a "stage g", specifically for the Antjam and Domaring beds of Borneo. He explained:

"It is of frequent occurrence that beds, free from Orbitoidides and situated above the Tertiary containing *Lepidocyclina*-*Miogypsina* are called 'Pliocene'. But when we do that, we forget the fact that there is not yet any certainty at all, as to whether the horizon of the Tjilanang beds may be correlated with the whole of the Vindobonian. It is quite possible that it only corresponds with two or one (or even less than that) of the sub-divisions of the Vindobonian (Helvetian-Tortonian-Sarmatian); in which case a part of the Tertiary; that is younger than the beds containing Orbitoidides, must be considered as belonging to the Miocene.

In Netherlands E. Borneo (Bulungan) the Miocene beds containing *Lepidocyclina* are followed immediately by the Antjam beds and the Domaring beds (Leupold) which are designated as Tertiary-g in 'Wetenschappelijke Mededeelingen No. 9' in which the Anthozoa of this horizon have also been described. It can serve no purpose to carry on the classification by letter any further as long as there are no data for fixing the boundaries and for ascertaining which organisms are distinctive".

H. Gerth (1931, p. 146) has pointed out that the Antjam beds contain two species of corals (*Astrocoenia minutissima* Gerth and *Hydrophyllia applanata* Gerth) belonging to genera unknown from the Pliocene or Recent and that these beds should therefore be considered as Miocene. Two years later, however, he transferred the first of these species to the genus *Stylophora* which is well represented in the Pliocene.

At the same time Leupold and van der Vlerk (1931) still avoiding the terms Miocene or Pliocene added a stage "h" to the letter-scale and quoted the following percentages of Recent mollusca in the higher stages:—

h	—50-60	per cent.
g	—35-45	" "
f ₃	—30	" "
f ₁₋₂	—8-20	" "

The percentage of recent species of mollusca appears to be the only feature defining stage "h", apart from the multitude of formations referred to it.

Stage "g" is defined by the Antjam beds as "type sequence", and by a fauna of mollusca containing 35-45 per cent. of Recent species. This appears to be an imaginary criterium as none of the five localities from which Martin described such assemblages belongs definitely to the "g-stage". According to Gerth (1931, p. 147) the Odeng beds with 43 per cent. are stratigraphic equivalents of the Tjilanang beds with 34 per cent. and f₃-lepidocyclines, while the fauna from shallow wells near Batavia with 36 per cent. is according to Rutten (1927, p. 102) probably Pliocene or Pleistocene. Furthermore, there is some doubt concerning the age and stratigraphic position of the Antjam and Domaring beds. The former overlie unconformably the Koendjang beds, age and foraminifera of which are unknown, and the latter overlie with apparent unconformity the Menkrawit beds (f₃) and are stated to correspond to the upper part of the Kampong Baroe beds which is Pliocene (Leupold and van der Vlerk 1931, pp. 619, 621, 624).

Apart from the rather unfortunate original definition, there is other evidence for the existence of an Uppermost Miocene stage without lepidocyclines. Le Roy's recent studies on smaller

foraminifera (1941) led to the conclusion that the Sangkoelirang beds are partly younger than Preangerian and older than Cheribonian, implying the existence of an intermediate stage corresponding in stratigraphic position to Umbgrove's stage "g". In parts of Java this intermediate stage is represented by unfossiliferous deposits, largely of volcanic origin (Genteng beds of West Java, Koembang beds of Central Java) which are followed by Lower Pliocene (Cheribonian). In Eastern Java the *Globigerina*-marls of the Lower Kalibeng beds (Duyfjes 1938) follow unconformably above the Rembang beds and are overlain by Pliocene Upper Kalibeng beds and Pleistocene Poentjangan and Kaboeh beds. A fauna of smaller foraminifera described by Koch (1923) from Kabu (Kaboeh) was apparently taken from the Lower Kalibeng beds. Koch remarks that in the definitely Pliocene fauna from the Fufa beds of Ceram (Fischer 1921, 1927) only very few species are extinct and that this fauna, therefore, must be younger. Most of the extinct species found at Kabu occur also in the Kar Nicobar fauna which Koch considered as Pliocene. He determined the age of the Kabu fauna as lowest Pliocene or Upper Miocene. Two "index species" are mentioned, *Uvigerina javana* Koch and a "*Globigerina* sp.". This was later named *G. kochi* Caudri (1934) but should be placed in *Sphaeroidinella*. Neither of these species has subsequently been found in definite Pliocene. Van Es (1931) assigns these *Globigerina*-marls from Kabu to the Uppermost Miocene, "g-stage". Duyfjes considers "the greater part of the Kalibeng beds" as Pliocene but appears to be prepared to admit Uppermost Miocene age of their lowest part. A fauna of smaller foraminifera described as "Miocene" by Yabe and Asano (1937) from West Java occupies a similar stratigraphic position.

There is no evidence anywhere of *Lepidocyclina* and *Miogypsina* having survived the Tortonian (possibly even Helvetian). As the vertebrate fauna proves post-Pontian age of the Cheribonian (Lower Pliocene of Java) and as it is generally assumed (Douvillé, Tan, and others) that the highest *Lepidocyclina*-bearing stage (Preangerian) corresponds to the Vindobonian (Helvetian-Tortonian), we expect to find an intermediate, or "g"-stage, of approximately Sarmatian-Pontian age.

It is admitted that more direct evidence of the existence and fauna of this stage must be awaited before it can be fully defined and named.

SIGNIFICANCE AND AGE OF THE FORAMINIFERAL DEPOSITS OF KAR NICOBAR AND FIJI.

Larger foraminifera, although known from many lithologically different rock types, are rare in argillaceous sediments and do not usually occur in rocks containing abundant pelagic foraminifera.

Many of these *Globigerina*-marls some of which may be stratigraphic equivalents of older *Lepidocyclina*-bearing rocks in different facies, have been classified as "Mio-Pliocene" or Pliocene on account of the absence of distinctive larger foraminifera. Undoubtedly, Indo-Pacific Tertiary smaller foraminifera can be utilized for distinctions between "*Globigerina*-marls" of different age and will be found not less useful for stratigraphic purposes than larger foraminifera when more detailed descriptive work is done. It is not possible to describe here new foraminiferal assemblages, but a critical review of the distribution of the smaller foraminifera known from the Tertiary of the East Indies, numbering about 650 species, shows that several well known species are restricted to Miocene deposits.

Until recently (Le Roy 1941), Schwager's work on Kar Nicobar (1866) and Cushman's work on Fiji (1934) were the only more or less complete descriptions of assemblages of Indo-Pacific Tertiary smaller foraminifera. Later work proved them to be representative of the whole Indo-Pacific Region. Although originally described as "Upper Neogene", they were both in recent years generally referred to the Pliocene. This classification which will be shown here to disagree with geological field data as well as with the composition of the fauna, made it impossible to distinguish between Miocene and Pliocene assemblages of smaller foraminifera.

Samples containing the Kar Nicobar fauna were taken by Hochstetter from some 20-30 feet of folded argillaceous rocks with sandstone bands overlain by young raised reef limestones. The argillaceous rocks of the Nicobar Islands were later included by Oldham (1885) in the Archipelago series. Tipper (1911) placed it in the Miocene. E. R. Gee (1926) found locally in Ritchie's Archipelago from which Oldham's stratigraphic term was derived, a late Tertiary, Pliocene or Pleistocene sequence of very loosely consolidated shelly mudstones containing numerous mollusca and occasional corals and echinoids, and a Miocene series of grey and greenish clays, argillaceous sandstones, white shelly limestone, and occasional conglomerates, representing the Archipelago series of Oldham, which is more affected by earth movements than the upper almost horizontal beds. This group includes foraminiferal limestones with *Lepidocyclina*, overlying clays on Wilson Island. While Tipper considered the Miocene Archipelago clays as younger than limestones with *Lepidocyclina* cf. *sumatrensis*, Gee found that similar limestones are interbedded in the Archipelago series. All geologists agree that the clays and sandstones of the Nicobar Islands belong to the Archipelago series which is Miocene, and is closely connected with *Lepidocyclina*-bearing rocks.

The foraminiferal assemblage described by Schwager contains 104 species, 34 of which occur in the Recent Pacific fauna. The percentage of Recent species is therefore 33. Forty-eight species

are also known from the Suva formation of Fiji; 53 species are recorded from other localities in the East Indies; 30 of these are extinct. Of this number 14 were found in the Bulongan fauna (Koch, 1926) with *Lepidocyclina* (stages e-f), 9 in the Uppermost Miocene (stage g), and 7 in Upper Miocene and Pliocene. The fauna shows relations only to Miocene assemblages of smaller foraminifera. The conclusion of a Miocene age of the Kar Nicobar fauna agrees with the revised age of the closely related Fiji fauna.

The age of the Suva formation of Fiji was recently discussed by H. Ladd (1934, p. 99 ff.) who tried to reconcile contradictory palaeontological data with each other and with the field evidence. The Suva formation is undoubtedly younger than the Viti limestone with *Lepidocyclina* (*Eulepidina*) *formosa* Schlumberger (e-stage). The majority of the earlier authors considered the larger fossils of the Suva formation as Miocene or early Pliocene. Among the "small and incomplete" molluscan fauna Ladd distinguished an older assemblage with 9.5 per cent. Recent species and a younger fauna with 21 per cent. Recent species. He found a number of species which had been recorded from Miocene only and accordingly placed the Suva formation in "Lower to Upper Miocene" (f and g stages) but admits, on the evidence of smaller foraminifera and corals the possibility of Pliocene age of part of the Suva formation.

In the light of later data Whipple's determination of the age of the Suva larger foraminifera as "e-stage" which according to Ladd disagreed with the balance of stratigraphic evidence, has to be modified. In the Suva area, in close proximity to the type section, the following assemblage of larger foraminifera was found: *Katacycloclypeus annulatus* (Martin), *Cycloclypeus neglectus* Martin, *Multilepidina suvaensis* (Whipple) (= *M. luxurians* Tobler sp.?), *Lepidocyclina* (*Trybliolepidina*) *aff. radiata* Martin, and several microspheric lepidocyclines described as *L. dilatata* (Michelotti), *L. dilatata* var. *laddi* Whipple (= *subradiata* H. Douvillé?), and *L. papulifera* H. Douvillé. This is a Rembangian assemblage (see Caudri 1939, locality 27b and others). The occurrence of a microspheric form described as *L. dilatata* is unimportant while the occurrence of *Katacycloclypeus* and *Multilepidina* which are unknown in the "e-stage", is decisive.

Ladd states (l.c., p. 95): "Cushman identified 95 species of smaller foraminifera from Station 371 which lies only 2 miles from the type section on Walu Bay and at about the same elevation. The same marls outcrop at many points between the two stations, and as all of them are horizontal it is certain that the marls of Station 371 are very close stratigraphically to the type section of the Suva formation."

In Cushman's publication (1934) 118 species of smaller foraminifera are described and most of them are figured. Approximately 64 species or 54 per cent. are Recent. Forty-eight

species occur also at Kar Nicobar. Of 28 extinct species also known from other localities not more than three have been recorded from both Miocene and Pliocene deposits, the others are known from Miocene. Of these, 10 come from beds originally determined as Miocene, 3 from Kabu, later assigned to the Upper Miocene, and 24 are known from Kar Nicobar.

The distribution of extinct species occurring in the Fiji fauna indicates Miocene age. The percentage of recent species is much smaller than in definitely Pliocene assemblages (88 and 94 per cent. in the Fufa beds of Ceram, 75 to 89 per cent. in Java) and lies between that of the Bulongan fauna (48 per cent., "e" or "f" stage) and that of the Kabu fauna (61 per cent., probably "g-stage"). The fauna of smaller foraminifera of the Suva formation of Fiji is therefore not Pliocene but Miocene and apparently contemporaneous with the Rembangian assemblage of larger foraminifera found in close proximity to the type section.

STRATIGRAPHIC POSITION.

The stratigraphic position of important known assemblages of smaller foraminifera from the Indo-Pacific Region is graphically shown in Table 1.

TABLE 1.

Series.	Stages.	Sumatra and Mentawai Islands.	Java.	Ceram, Borneo.	Fiji.	Per cent. Recent Species.
Pliocene	Bantamian	—	Bodjong* LR West Java* YA	Ceram* F, K	—	>70
	Sondian	—	Sonde* BV	—	—	
	Cheribonian	—	—	—	—	
Miocene	"g"	"Fluvio-brackish" LR Siberoet LR	Kabu K West Java YA	Sangkoelirang LR	—	60-70
	Preangerian	"Transitional"* LR Kar Nicobar S Telisa* LR	—	↓ ?	} Suva C	<60
	Rembangian		—	Bulongan* K		
	"e"	—?—	—	↓ —?—	—	?

(Explanation of abbreviations and symbols used :

Authors' names—

LR—L. W. Le Roy 1939, 1941.

YA—H. Yabe and K. Asano 1937.

BV—L. Boomgart and J. Vroman, 1936.

F—P. Fischer 1921, 1927.

K—R. Koch, 1923, 1925, 1926.

C—J. A. Cushman 1931, 1934.

S—C. Schwager 1865.

Arrows indicate that the fauna or part of it may be older.

Assemblages shown as extending over more than one stage may but do not necessarily represent the whole of these stages. * designates age determinations suggested by the authors named).

The figures for percentages of Recent species included in Table 1 are approximate. They are based on the following results of counts and calculations which owing to limitations of space cannot be fully discussed here:—

STAGES "e-f":

Telisa, "Transitional" (Le Roy)	..	..	24 per cent.
Kar Nicobar (Schwager)	..	..	30 " "
Bulongan (Koch)	..	..	48 " "
Fiji (Cushman)	..	..	54 " "

STAGE "g":

Sangkoelirang (Le Roy)	..	..	60 " "
Kabu (Koch)	..	..	61 " "
West Java (Yabe and Asano)	..	..	65 " "
Siberot (Le Roy)	..	..	69 " "

PLIOCENE:

Bodjong (Le Roy)	..	..	73 " "
West Java (Yabe and Asano)	..	..	86 " "
Ceram (Koch)	..	..	88 " "
Sondé (Boomgart and Vroman) (includes Pleistocene)	..	..	89 " "
Ceram (Fischer)	..	..	94 " "

It is not correct to assume that within the limits of the stages the fauna with the lower percentage is necessarily older. The transition from Miocene to Pliocene is evidently accompanied by a more rapid and therefore clearly expressed change in the composition of the foraminiferal fauna which definitely advanced the previously and subsequently fluctuating ratio. This gives an approximate indication of the age of an assemblage of foraminifera equal in value to the different and much lower percentages of Recent molluscan species.

MIocene INDEX FORAMINIFERA.

Of greater importance for stratigraphic correlation are index species of known, restricted, vertical range. The ranges of certain important larger foraminifera are shown on the accompanying chart, according to the latest available data. The following tentative list of selected species of smaller foraminifera, all recorded from more than one locality, is based entirely on published data arranged according to the chart (p. 67). These data do not enable us yet to distinguish index species for the different stages of Miocene and Pliocene among the smaller foraminifera but they prove that a considerable number of important Miocene species have never been found in younger deposits. Some of them are placed on record in the following list:—

- Austrotrillina howchini* (Schlumberger).
- Bifarina crenulata* Le Roy.
- Bulimina microlongistriata* Le Roy.
- Cassidulina murrhyna* (Schwager).
- Cassidulina bicornis* (H. B. Brady).
- Chrysalogonium polystoma* (Schwager).
- Cibicides fijiensis* (Cushman).

- Cibicides dorsopustulosus* Le Roy.
Clavulinoides szaboi (Hantken).
Dentalina stimulea (Schwager).
Dorothia subrotundata (Schwager).
Eggerella? *subovalis* (Schwager).
Eponides multiseptatus (Koch).
Gaudryina solida Schwager.
Karrerella siphonella (Reuss).
Lagena castrensis Schwager.
Lagena schwageriana Cushman.
Listerella victoriensis Cushman.
Marginulina subtrigona Schwager.
Marginulina subbullata Hantken.
Nodosaria arundinea Schwager.
 " *crassitesta* Schwager.
 " *equisetiformis* Schwager.
 " *hochstetteri* Schwager et var.
 " *inconstans* Schwager.
 " *koina* Schwager.
 " *skobina* Schwager.
Pulvinulinella bengalensis (Schwager).
Pyrulina labiata (Schwager).
Robulus javanus (Koch) et var.
Siphonina australis Cushman.
Siphonodosaria adolphina (d'Orbigny).
 " *maculata* (Schwager).
 " *insolita* (Schwager).
 " *setosa* (Schwager).
Sphaeroidinella kochi (Caudri).
 " *seminulina* (Schwager).
Textularia solita (Schwager).
Uvigerina gemmaeformis Schwager.
 " *hispida* Schwager.
 " *javana* Koch.
Vaginulina perprocera (Schwager).
Vaginulinopsis gradata Thalmann.
Vulvulina nicobarensis (Schwager).

5. FURTHER PROBLEMS OF TERTIARY CORRELATION.

Much further work on stratigraphy and palaeontology of the Pacific Islands is required before the stratigraphic classification of the Tertiary sediments developed in the key areas of the East Indies can be extended over the whole Indo-Pacific Region. The main problems can be outlined as follows:—

(1) Correlation of the two post-Aquitania Miocene stages (Rembangian and Preangerian) characterized in Java and elsewhere by distinctive species of mollusca, larger and smaller foraminifera.

(2) Confirmation of the existence of the Uppermost Miocene stage "g".

(3) Correlation of the Cheribonian, Sondian, and younger molluscan faunas of Java which are known to represent the European Pliocene and Pleistocene on account of their relations to vertebrate-bearing beds, with the molluscan faunas of the same age from New Guinea and other islands.

(4) Study of the smaller foraminifera of the "Younger Tertiary" deposits reported from many islands between New Guinea and Tonga, with special reference to stratigraphic ranges, recognition of species restricted to the Miocene, and the gradual increase in the number of Recent species in younger deposits.

Faunal relations between the surprisingly uniform Tertiary of the Indo-Pacific Region and that of South-eastern Australia and New Zealand are limited and are either created by "eurythermic" species which were able to cross the boundary of the tropical belt or by short-lived climatic or ecologic changes creating a suitable environment for warm-water species and genera. In the Tertiary of Victoria the Batesfordian containing a group of *Lepidocyclines* as well as *Austrotrillina* and perhaps some other Indo-Pacific smaller foraminifera forms a short-lived link with the Indo-Pacific Region. I. Cressin (1941, p. 254) concludes "The Middle Miocene age is supported by a close study of the *Lepidocyclinae* (so characteristic of this stage) and *Cycloclypeus* and their relationships with Indo-Pacific assemblages".

In New Zealand "*Miogypsina* appears for the first time, and is abundant in, and limited to, the Hutchinsonian. This also applies to our various species of *Lepidocyclina*, which are all *Nephrolepidina*". (Finlay and Marwick 1940, p. 94.) Mr. W. J. Parr drew the writer's attention to the fact that F. Chapman had described *Lepidocyclina* (*Eulepidina*) *dilatata* (Michelotti) from Hokianga South Head, North Auckland, McKay's loc. 733 (F. Chapman, The Cretaceous and Tertiary Foraminifera of New Zealand. N.Z. Geol. Survey, Pal. Bull. No. 11, 1926, p. 93, pl. 20, f. 1) Material from this locality which was kindly made available by Mr. Parr from his rich collections, proves beyond doubt that a typical *Eulepidina* occurs in New Zealand, together with an undescribed species of *Nephrolepidina*, and also, according to F. Chapman (l.c.) together with *Miogypsina irregularis* (Michelotti). The species of *Nephrolepidina* mentioned by Finlay and Marwick have not been described or figured from New Zealand. These authors place the Hutchinsonian in the "Lower Miocene".

Specific features and generic ranges of the majority of the Indo-Pacific larger foraminifera differ considerably from species and distribution of the same useful group of fossils in tropical

Central America. Owing, perhaps, to the vast distance in space or to the absence of Tertiary land bridges across the Pacific Ocean which would have provided suitable shallow-water environment, faunal links are extremely rare. In this respect the smaller foraminifera show very promising signs of inter-continental relations. To any student of the Indo-Pacific Miocene smaller foraminifera, the Bowden fauna of Jamaica or the fauna of the Port-au-Prince beds of Haiti recently described by Coryell and Rivero (Journ. of Paleont., vol. 14, No. 1, 1940), appear strikingly familiar. The uncertain stratigraphic position of Indo-Pacific Tertiary foraminiferal assemblages has hitherto prevented authors from attempting trans-Pacific faunal correlations. This work remains outside the scope of the present review.

III. Notes on the Geological History of the Indo-Pacific Region.

1. The relations of the Jurassic of New Guinea, North-western Australia, New Caledonia, and New Zealand suggest the existence of a Jurassic Circum-Australian geosyncline connected with the Timor-East Celebes geosyncline and linked with the Tethyan sea in the Himalaya.

2. While there are indications of a marine transition from Jurassic to Lower Cretaceous in the Timor-East Celebes geosyncline, pre-Aptian marine Cretaceous deposits appear to be absent in Australia and New Guinea. A similar but still ill-defined break is found between Jurassic and Cretaceous in New Caledonia. The time of this break corresponds to the important epi-Jurassic (Pacific or Young Kimmeric) phase of folding in New Zealand and elsewhere.

The time following immediately after the close of the Jurassic Period, shows throughout the area of the Jurassic Circum-Australian geosyncline clear signs of what Sir T. W. E. David, referring to Australia, called a "vast geographical change" (1932, p. 171). Aptian, Albian, Cenomanian, and possibly also Barremian are locally transgressive on Jurassic, Triassic, and older beds. The geographical continuity of the Tethyan fauna is temporarily interrupted by ecological (climatic?) and possibly also topographic barriers.

3. The range of *Globotruncana* rocks throughout the area shows that in the Senonian Epoch the Mediterranean (Tethyan) affinities in the Circum-Australian zone are restored, at least as far as planktonic foraminifera are concerned. The typically Mediterranean Senonian larger foraminifera (*Orbitoides*, etc.) are not yet known beyond Northern India and Burma, and there are certain specifically Pacific features in the Upper Cretaceous molluscan fauna.

4. Throughout the region east of Burma no fossiliferous deposits of Uppermost Cretaceous (Danian) or Lowest Tertiary age are known. The Eocene rest generally unconformably on older rocks (Umbgrove 1938, Table 6).

The late Cretaceous Laramic orogeny must have finally broken the continuity of Tethyan faunal relations. Epi-Cretaceous folding movements are reported to be widespread throughout the Timor-East Celebes geosyncline and extended probably to New Guinea where conditions before the end of the Cretaceous Period reverted to geosynclinal, and to New Caledonia. The Westralian part of the former Circum-Australian geosyncline shows according to Raggatt (1936) no signs of movement after the deposition of a typically epicontinental series of Upper Cretaceous sediments.

5. The difference between the western and eastern parts of the Circum-Australian area of Palaeogene deposition is very marked.

Umbgrove (1938, p. 34) states that in the East Indies "all marine Palaeogene sediments have been deposited in shallow epicontinental seas (neritic and littoral). The strong relief as we know it at this moment—the many deep sea basins—originated much later".

In south-eastern New Guinea and New Caledonia the Eocene is rich in siliceous rocks, partly containing abundant radiolaria, and is affected by basic intrusions. Although the presence of intercalated beds with abundant nummulites and other larger foraminifera makes an abyssal origin of the siliceous rocks improbable, their geosynclinal character can hardly be denied in view of many examples of similar rocks formed in pre-Tertiary geosynclines. More than purely ecological differences between the two areas appear to be expressed in this inequality of Palaeogene deposition. It is probably connected with the important "diversity of structural controls" between the Australian-Asiatic and the Australian-Pacific boundary zones, which was first postulated by W. N. Benson (1924, p. 133). If the existence of a similar development of siliceous rocks and basic intrusions in late Cretaceous and early Palaeogene time in the Arakan Yoma-Andaman arc is confined, then these occurrences would point to a remarkable parallel between the border zones of the Indian Ocean and of the Pacific.

6. During the Palaeogene and Miocene enormous thicknesses of sediments began to accumulate in some basins of gradual subsidence within the generally epicontinental and more or less stable areas. Umbgrove refers to these remarkable basins as "idiogeosynclines". North and South-east Sumatra, the central

belt of Java, and several basins in East Borneo are examples of such areas which contain the richest oil-bearing strata of the East Indies (Umbgrove 1938, pp. 39 ff., and also in: Vening Meinesz 1934, pp. 155 ff.).

Most of these idiogeosynclines began their existence later, in early Miocene time, partly in connection with a widespread transgression which Umbgrove named "Beboeloeh transgression" dating it as Upper Aquitanian (e_5). Other authors are only prepared to admit that transgressions occurred between Upper Oligocene and Lower Miocene. Several idiogeosynclines appear to have existed in the New Guinea area. Sedimentation in the idiogeosynclines ended generally in the Pliocene with the deposition of sediments in paralic facies (shallow water marine beds with coal and non-marine intercalations). The idiogeosynclines have been subjected generally to folding in late Pliocene and Pleistocene time.

On the north coast of New Guinea, in New Ireland, and in the Solomon Islands some of the widespread *Globigerina*-sediments belong to the Pliocene and Pleistocene. Locally even very young chalky radiolarian rocks are known (Tan Sin Hok 1926). This pelagic fauna and sedimentation indicates free connection with the open sea along the outer Pacific border rather than young submergence to abyssal or bathyal depth of these areas which are at present definitely rising.

7. The old Timor-East Celebes geosyncline, while not known to differ from adjoining areas in Tertiary sedimentary history, is characterized by strong intra-Miocene folding. According to the Dutch geologists a belt of less intensive folding follows the West coast of Sumatra and the South coast of Java and extends further eastwards.

8. Areas of more or less undisturbed Tertiary are found on the Sahul shelf and in North Celebes. Sundaland, including the east coast of Sumatra, the Malay Peninsula, and Western and Central Borneo, had become stabilized and was in Tertiary time above sea level. Plio-Pleistocene folding and uplift joined the area of the surrounding idiogeosynclines to that of Sundaland the Pleistocene outline of which is believed to be marked by a subsequently submerged shelf.

On the Sahul shelf and in North-western Australia mainly coralline and foraminiferal limestones were deposited in Tertiary time. In the former area the same type of sedimentation appears to continue to the present time while in the latter late Miocene or Pliocene folding or warping created wide folds with low-dipping flanks (Raggatt 1936, p. 169).

9. Data on the geology of New Guinea and other Pacific Islands are insufficient for general statements on their Tertiary history. Umbgrove considers late Miocene folding of the Main Range of New Guinea as possible and van Bemmelen (1939) assumes a Burdigalian (Rembangian) phase of folding followed by renewed Upper Miocene-Pliocene sedimentation. There is also ample evidence of Plio-Pleistocene folding. Fiji and Tonga, belonging to a stable area beyond the Circum-Australian folded belt, were subjected to uplift commencing in Miocene time (Ladd 1934, Hoffmeister 1932).

10. Our knowledge of the important young or Recent movements in the Pacific Islands will be greatly advanced when "raised reef limestones" and foraminiferal sediments will be assigned to the various Tertiary stages which some of them undoubtedly represent, or to the Quaternary, according to their fauna. In many earlier reports they have been summarily described as Recent or Pleistocene deposits in accordance with their often misleading general appearance. Recent work in the Fiji and Tonga Islands as well as Mr. F. Chapman's and Miss I. Crespin's numerous contributions to the problem show the paramount importance of the results of modern biostratigraphic work in the East Indies as a base for our understanding of the whole Indo-Pacific Region.

It is hoped that the critical review presented here will contribute, by stimulating discussion of the problems outlined, to further progress.

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