BIOGEOGRAPHY OF SOME EOCENE LARGER FORAMINIFERA, AND THEIR APPLICATION IN DISTINGUISHING GEOLOGICAL PLATES

Peter Lunt

ABSTRACT

Indo-Pacific Eocene carbonate sediments can be divided into two groups based on the presence of certain larger foraminifera. One of these faunal groups is associated with the Sundaland craton, the geological core of western Indonesia and is also found on low latitude Pacific islands as well as low latitude western Tethyan regions. The second fauna is found on the Australian Plate, and the micro-plate terrains have been derived from it since the Eocene.

This correlation leads to the hypothesis that the Middle and Late Eocene Sundaland fauna, identified by the three, probably related genera: *Assilina, Pellatispira,* and *Biplanispira* [hereafter abbreviated to "APB"] indicate a low latitude, shallow marine fauna, able to cross oceanic migration barriers but restricted from migrating far outside the tropics. In contrast, the fauna identified by the genus *Lacazinella*, which has about the same stratigraphic range as the APB lineage, is thought to be a higher latitude fauna centered on the Australian continent.

This faunal difference occurred at a time of maximum separation of the Sunda and Australian plates. Therefore, subsequent Tertiary collision of these plates can be identified by the present complex distribution of previously separate faunas, and a tectonic suture can be plotted for the collision area in Eastern Indonesia/Papua, which generally agrees with other geological data.

To partially test this hypothesis some Eocene limestone samples from Christmas Island were collected and studied. This oceanic guyot is now slightly closer to Indonesia than Australia, but in Eocene times it would have been much further south. In this location neither APB or *Lacazinella* were found. Instead the fauna is dominated by small *Discocyclina* and *Grzybowskia*, the first record of the latter genus in the Indo-Pacific area. The few known species of *Grzybowskia* are recorded from the Boreal region of Europe, in strata usually assigned to the Late Eocene. This new record suggests *Grzybowskia* is, somewhat like *Lacazinella*, a higher latitude form but with representatives on both sides of the Eocene equator.

A new species, *Grzybowskia jasoni* sp. nov. is described.

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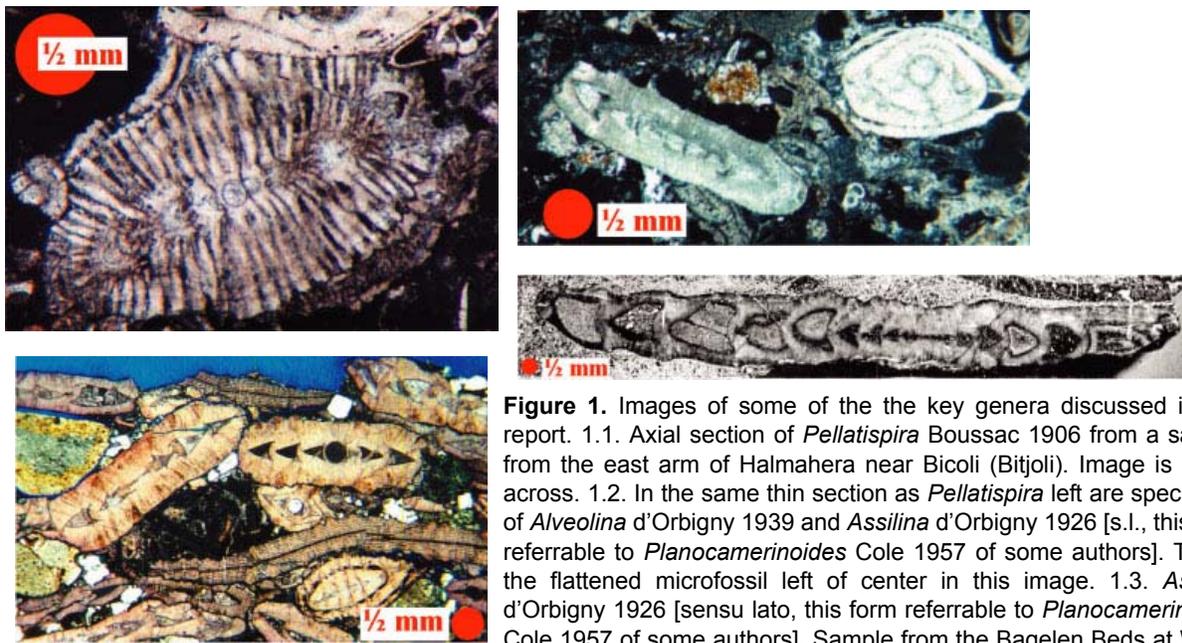
Figure 1. Images of some of the the key genera discussed in this report. 1.1. Axial section of *Pellatispira* Boussac 1906 from a sample from the east arm of Halmahera near Bicoli (Bitjoli). Image is 3 mm across. 1.2. In the same thin section as *Pellatispira* left are specimens of *Alveolina* d'Orbigny 1939 and *Assilina* d'Orbigny 1926 [s.l., this form referrable to *Planocamerinoides* Cole 1957 of some authors]. This is the flattened microfossil left of center in this image. 1.3. *Assilina* d'Orbigny 1926 [sensu lato, this form referrable to *Planocamerinoides* Cole 1957 of some authors]. Sample from the Bagelen Beds at Worowari, Central Java, personal collection. 1.4. Reproduced out of Douvillé 1912, from Nias. *Assilina* sp. This is now considered *Assilina* s.s. with no spiral sheets extending to the umbonal areas.

INTRODUCTION

After many years examining field and well samples of *Nummulites* and *Discocyclina* dominated limestones (Eocene, generally shallow marine) from eastern Indonesia, an association of secondary larger foraminifera was noted to correlate with plate tectonic divisions. A review of published data and proprietary industry records strengthened and extended this palaeogeographic correlation.

In order to partly test this hypothesis, a visit was made to Eocene limestones of Christmas Island. Christmas Island faunas occur between the two aforementioned faunas but had not yet been described in detail. The short accounts available mentioned neither of the palaeogeographic marker taxa. The new samples showed that the apparent low diversity implied by previous summaries was real and not just a limitation of effort in study. The large number of polished and thin sections made for this study made it possible to identify that an abundant Heterostegine form was quite distinct and unusual, being a new species of the Boreal genus *Grzybowskia*. This is the first record of this genus in the Indo-Pacific area or the southern hemisphere, and a summary of the distribution of this taxon also shows a strong palaeogeographic control. The reasons for including this species in *Grzybowskia*, and hence for adding an additional palaeogeographic index taxa to the biogeographic reconstruction, are discussed below.

A few reports of the APB fauna from the Australian plate in oil industry biostratigraphy studies (mostly from western Papua) have been investigated and, when original thin sections were still available, found to be incorrect. It should be noted that the APB genera have some difficulties in identification, especially in random thin sections.

Assilina can be confused for flat forms of *Operculina*, and the usually distinctive *Pellatispira* has been confused with ornamented rotaliid forms, especially by industry biostratigraphers who are accustomed to examining planktonic foraminifera. *Lacazinella* is strikingly unique and hard to mistake.

In the records discussed here no attempt has been made to distinguish *Assilina* d'Orbigny 1839 from *Planocamerinoides* Cole 1957, in the sense of Haynes (1988) and others, who place fully evolute forms (in the adult stages, Figure 1.4) in *Assilina*, and quasi-evolute forms (with spiral sheets extending over the previous whorls) in the latter genus (e.g., Figure 1.2 and Figure 1.3). Both taxa occur in the Indo-Pacific region, but most work was done during prior to the original or revised definitions of *Planocamerinoides*. Not all records are illustrated, and therefore new taxonomies cannot be suggested.

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Environmental range of the genera

Both the APB and *Lacazinella* larger foraminifera usually occur as minor components in Eocene carbonates where the cosmopolitan genera *Discocyclina* and *Nummulites* are dominant. This similar minority role suggests that the presence or absence of either of the markers is probably not related to gross lithologic or sedimentological effects. However, the genera *Assilina, Pellatispira,* and *Biplanispira* usually occur only in a sub-set of samples from any particular Eocene locality, suggesting there is some local environmental control on its distribution.

Lacazinella has a different local distribution pattern, occuring commonly in low diversity assemblages (e.g., Figure 6), interbedded with more coralline limestones without *Lacazinella* but containing *Discocyclina* and *Nummulites*. Because of this more stratified distribution, and the fact that it is a miliolid form, *Lacazinella* has been interpreted as an indicator of back-reef facies. In my experience I have never observed more than a trace of planktonic foraminifera in the micritic limestone that hosts the most abundant *Lacazinella* faunas. However, *Lacazinella* is reported from several locations on the Onin Peninsular area of west Papua (Visser and Hermes 1962) and nearby Pisang Islands (Rutten 1936), in a facies trend mapped by Visser and Hermes (enc. 10, part V) as "open marine, .. non reefal aphanitic limestones with predominance of planktonic foraminifera." Also Apthorpe (1988) describes the widespread Hibernia limestone of the Australian Northwest shelf as being characterised by monospecific *Lacazinella* assemblages - a wide distribution not typical for restricted back-reef facies. Other supposed back reef miliolid indicators such as *Alveolina* are found in some Australian T.a stage (Middle Eocene) limestones but usually with *Nummulites* and not with *Lacazinella* faunas. All this information suggests the *Lacazinella* assemblages may have occupied a much more widely developed environmental setting than restricted back reefs habitats. More methodical observations are needed to clarify this hypothesis.

Stratigraphic range of the genera

In the Indo-Pacific area *Assilina* is used to identify Middle Eocene carbonates, and a short overlap with *Pellatispira* then occurs during latest Middle Eocene followed by *Pellatispira* and *Biplanispira* in later Eocene carbonates (pers. obs., in contrast to Adams 1970). This biostratigraphy is one of the fundamental components in identifying Letter Stages T.a and T.b (Figure 2; van der Vlerk and Umbgrove 1927 and later revisions).
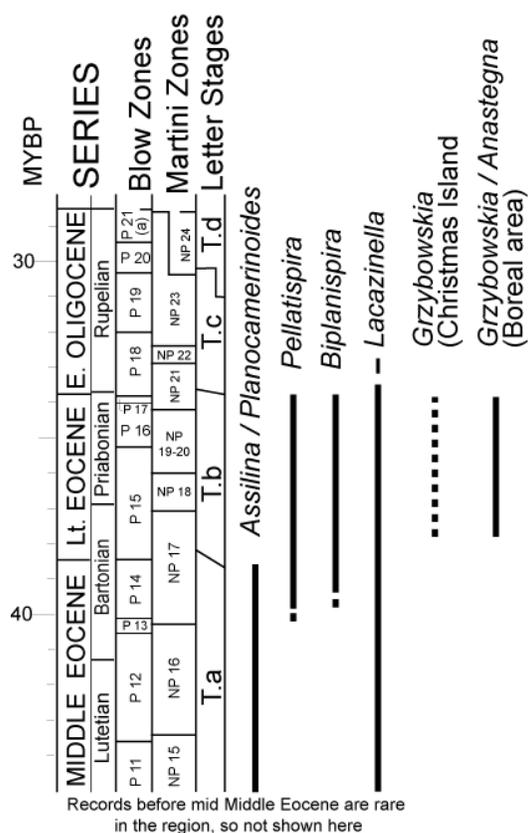
Figure 2. The stratigraphic ranges of the taxa discussed plotted against a time scale based on Berggren et al. (1995), with larger foraminifera Letter Stages calibrated based on unpublished data.

Dating Australian shallow marine carbonates using the Indo-Pacific Letter Stages is therefore difficult in the absence of the APB lineage. *Lacazinella* is reported from beds considered as T.a (approximates Middle Eocene) on the basis of associated *Nummulites* species such as *N. bagelensis* or large forms with meandrine septal traces [Rutten 1936, Crespin 1962, and possibly Bain and Binnekamp 1973]. The other T.a age index genus, *Alveolina*, is found in both Sundaland and Australian regions but it is an uncommon form, suspected to be environmentally restricted (see notes above).

Lacazinella continues through T.b (Late Eocene) and appears to share the same abrupt extinction as general Eocene forms such as *Discocyclina*. However, Bursch (1947) described *Lacazinella* occurring with reticulate *Nummulites* in Kai Besar (Figure 3, location 3 on map). Adams (1970) confirmed *Nummulites fichteli* with *Lacazinella* in Bursch's material, which therefore appears to extend the range of the genus into Letter Stage T.c, Early Oligocene.
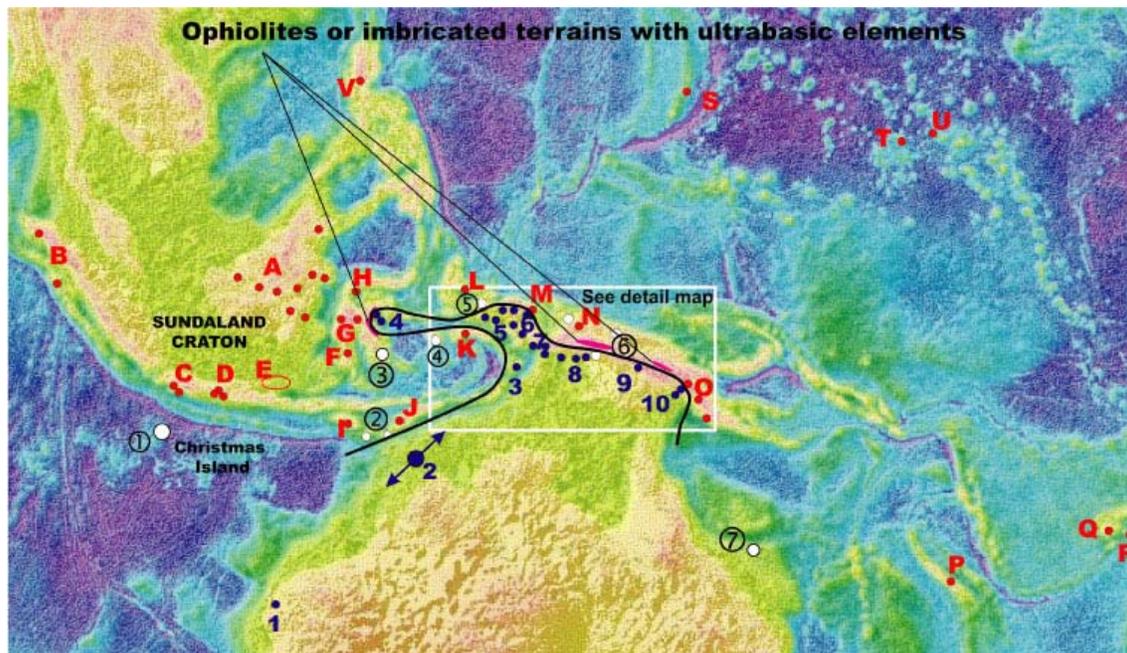
Figure 3. Summary of *Assilina/Pellatispira/Biplanispira* and *Lacazinella* faunas in the Indo-Pacific realm. Global Sea floor Topography from Satellite Altimetry, by Smith, W.H.F.and Sandwell, D.T. 1997. Available on the National Geophysics Data Center introductory page, with the image below being an extract from this file.

Lacazinella has been reported from the Late Paleocene of Oman by White (1994), but the significance of this temporally and geographically isolated species in not known.

Geographic range of the genera

Figure 3, Figure 4, Appendix 1, and Appendix 2 illustrate the geographic spread of records of the genera.

To summarise here I need only to stress that there is just a single known exception to the mutually exclusive distribution of the two faunas (Crespin 1938, in the Chimbu Gorge of Papua New Guinea). Even if this exception is evidence that the APB fauna could migrate in small numbers to the northern fringes of the high palaeo-latitude Australian plate, it is a minor exception and unrelated to the total absence of *Lacazinella* from low latitudes in the Eocene.

Taxonomic considerations of the APB fauna

Both Boussac (1906) and Umbgrove (1928) considered *Pellatispira* (which then still included *Biplanispira*) and *Assilina sensu lato* as being "closely allied" taxa, with the implication that the thick-walled assiline (Planocamerinid) forms could be both stratigraphically and morphologically the ancestor to the pellatispirine types. Since then no missing link such as a pellatispirine species associated with an assiline juvenile stage has been found. Furthermore, the most recent work of Hot-

tinger et al. 1991 on pellatispirines has increased the morphologic differences between the two taxa by clearly showing the so-called marginal cord of *Pellatispira* is a very different structure from the nummulitic cord (although some evolutionary link between the two features cannot be ruled out). The similar latitudinal association of the taxa presented here is weak data supporting the idea of a phylogenetic link between the two forms.

The work of Hottinger et al. 1991 clearly shows the close relationship of *Pellatispira* and *Biplanispira*, as emphasised by the adult of the former often forming the juvenile stage of the latter.

CLIMATE AND THE POSITION OF MAJOR PLATES IN EOCENE TIMES

A wide range of data, most directly oxygen isotopic measurements (Pearson et al 2001) indicate that in the Eocene the global climate was warmer than it is now. From this data we can extrapolate that what we now consider "tropical" faunas would have occupied a wider latitudinal zone (the astronomically defined Tropics of Cancer and Capricorn being unchanged). Therefore warm water, photic foraminifera with larger tests would probably have been major rock- forming organisms at higher latitudes than they were in later Tertiary or modern times.

In the Eocene, the northern edge of the Australian plate would have been around 2,000 kms to
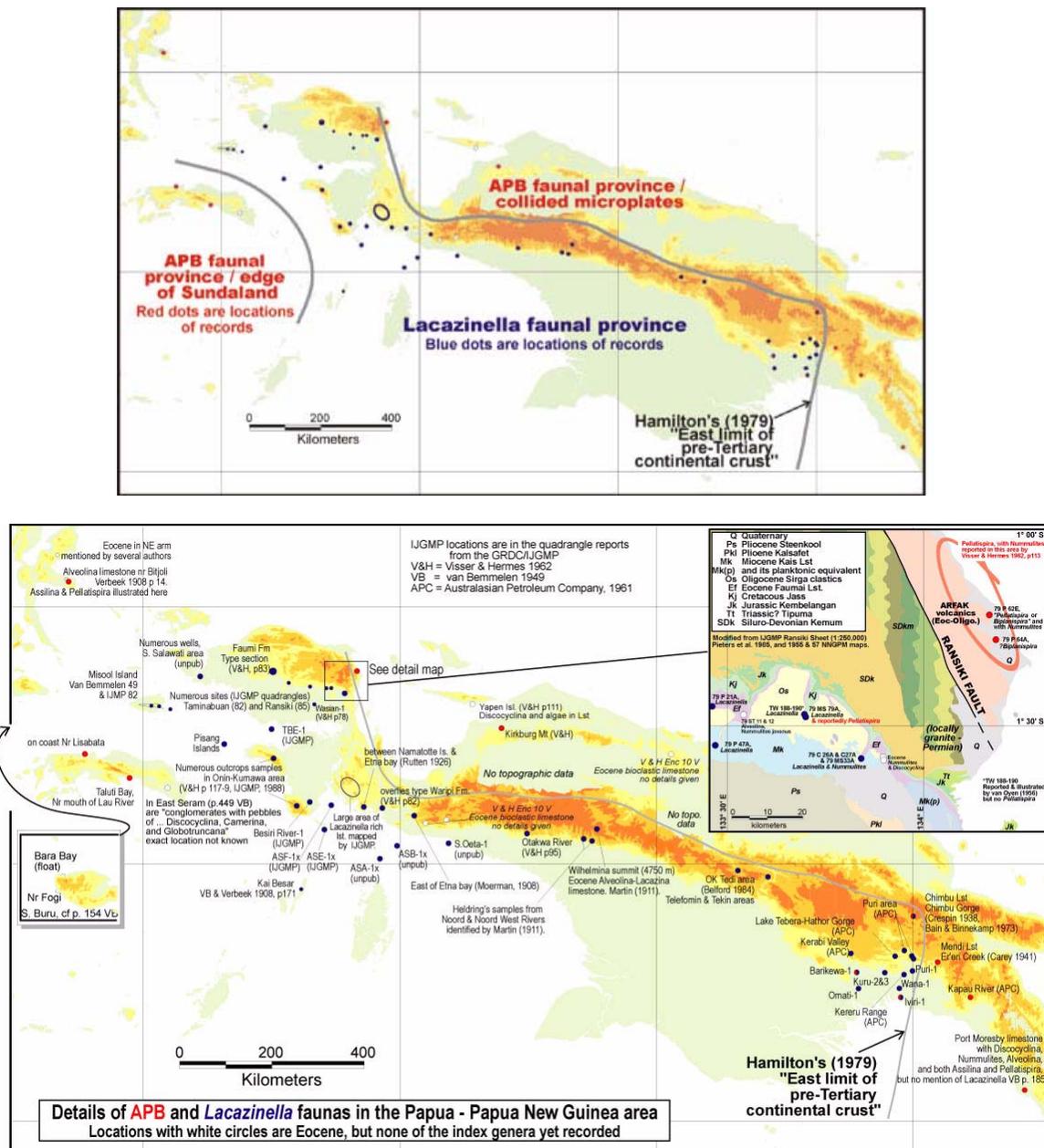
Figure 4. Grouping of foraminiferal faunas around the northern margin of the Australian Plate.

2,800 km further south of its current location, based on 5 to 7 cm of drift per year over 40 Ma (Le Pichon 1968, Veevers et al. 1991) (Fig. 5). Under the prevailing warm Eocene climate even this southerly location was obviously quite capable of supporting highly active biohermal organisms, and many hundreds of feet of carbonate rocks were deposited over a huge shelf area.

The records of Eocene carbonate faunas from the widely spaced Pacific islands show that the APB genera were able to migrate over large dis-

tances of open ocean (This also applies to the associated genera *Nummulites*, *Discocyclina*, and others.). Therefore, there is no reason to think there were any significant migration barriers to cause the differentiation of the APB and *Lacazinella* faunas. There is still no data indicating that *Lacazinella* was able to migrate over oceanic distances, although reports of this genus from the Late Paleocene of the Middle East (White 1994) might have impact on this subject. It is possible that the APB-*Lacazinella* faunal differentiation was
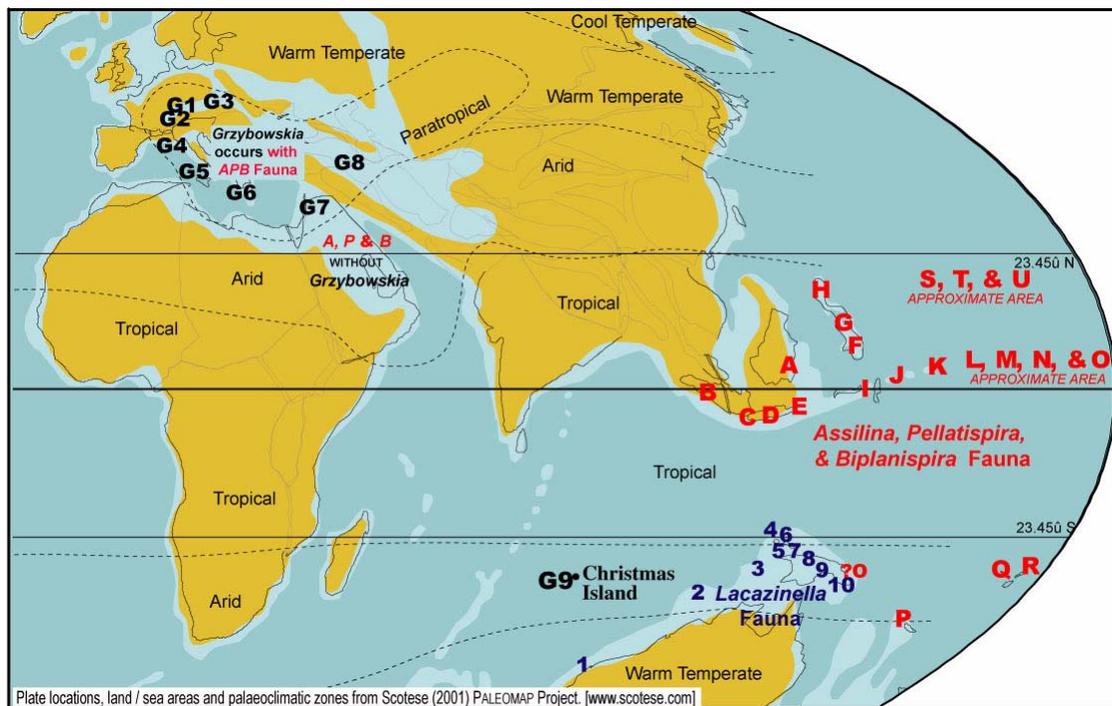
Figure 5. Middle and Late Eocene plates and climatic zones (Scotese 2001) with locations of "APB" fauna in red, *Lacazinella* fauna in blue, and the genus *Grzybowskia*. In shallow marine carbonate facies the APB fauna appears to dominate the tropics but can occur locally at higher latitudes, whereas *Lacazinella* is a high latitude Austral index. *Grzybowskia* is also a high latitude form mostly known from the Boreal region but now recorded from the southern hemisphere. Letters and numbers in the map are explained in Appendix 1. The Tropics of Cancer and Capricorn are marked at 23.45 north and south, respectively:

G1: Type location *Grzybowskia*, Polish Carpathian M
G2: Type location *Grzybowskia reticulata* (Rütimeyer 1850), Switzerland
G3: Hungary, Jambor-Kness 1988, H. reticulata Rütimeyer
G4: Nr. Trento N. Italy, Bonneau 1969
G5: NW. Sicily, Montanari 1969
G6: Western Pelóponnisos, Dercourt et al. 1970
G7: Syria, Ejel 1969
G8: Armenia and Georgia, (Gabrieljian), Kacharava and Kacharava 1962
G9: Christmas Island, this report

an effect related to the difference in latitude in Eocene times, such as a variation in light intensityor tolerance of seasonality. Seasonal variation is an environmental factor that greatly increases outside the true geographic tropics and is therefore not a condition seen as clearly in younger Tertiary or modern biohermal carbonate facies that are restricted to the true tropics. It is therefore possible that *Lacazinella* was adapted to warm water conditions but also a summer-winter (solstice to solstice) cycle, and it may have been this, or a related factor, that kept the APB fauna from establishing itself in the south. More work on the northern Indo-Pacific distribution of APB faunas would shed some light on this hypothesis, if enough Eocene carbonates can be found and studied.

IMPLICATIONS FOR PLATE TECTONIC RECONSTRUCTIONS

The modern distribution of rocks containing Australian (*Lacazinella*) and Sundaland to wider Tethyan (APB) microfossil faunas on the whole follows expected patterns, with ophiolite complexes and major fault zones occurring along zones of collision between these once separate plates (e.g. in Papua, see Figure 3, modified from Hamilton 1979). The identity and tectonic evolution of the major plate units are not in doubt. It is in assigning Sundaland or Australian origins to the minor plate fragments that these fossils will be of most use.

Many islands that make up the Banda Arc, including Sumba, parts of Timor, and Seram have
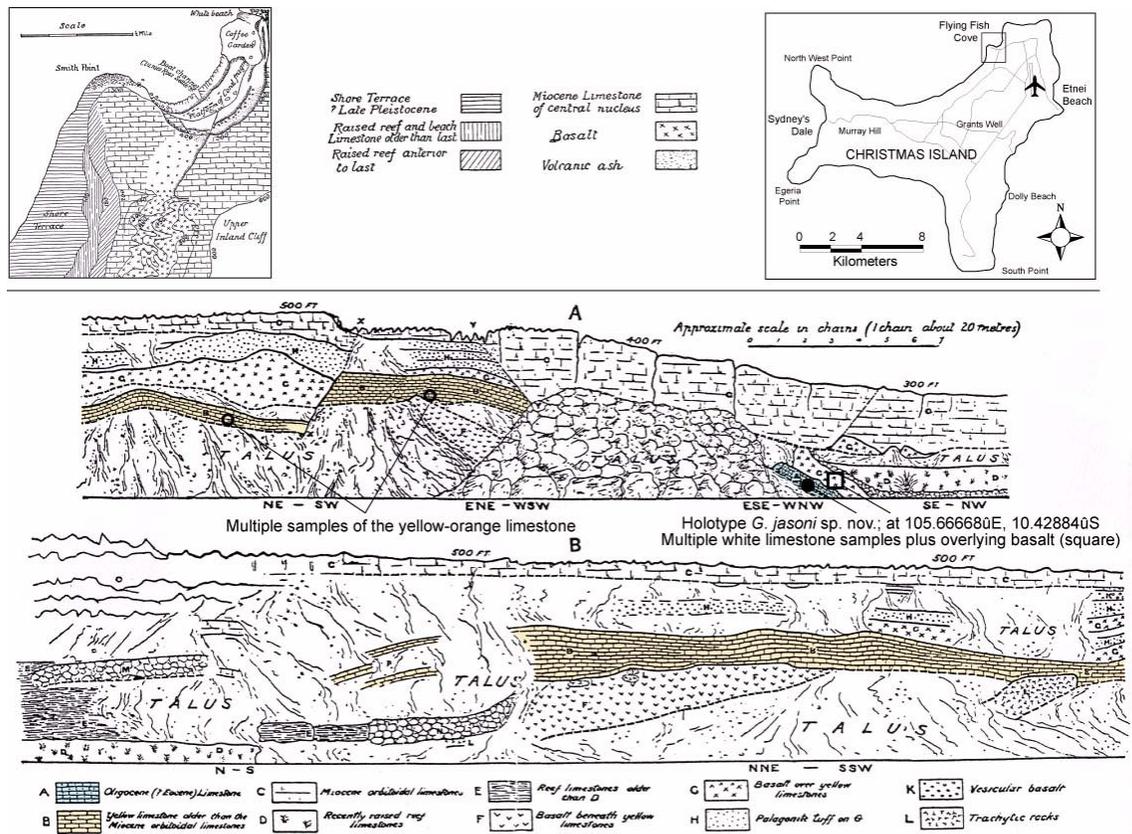
Figure 6. The location of the Eocene samples from Christmas Island. Sketch of the island (right), Flying Fish Cove enlarged (left) in a geology map from Andrews (1900, p. 281). Key below. Lower page: sketches from Andrews (p. 272) of the Flying Fish Cove outcrops. "A" is the south cliff, "B" is the north cliff, although this NE part of the cove is now obscured by port facilities.

records of the APB fauna. This similarity indicates that they were separate from the Australian plate and at low latitudes in Eocene times. Assuming the palaeomagnetic anomaly "M25", end mid-Jurassic rift-drift event was the last known cause for separation of micro-plate fragments from the Australian margin (cf. Veevers et al. 1991), then these fragments would have been carried north and become accreted onto the subducting margin south of Sundaland within the Cretaceous. Such a model does not match tectonic histories proposed in many recent publications. For example, Hall (1996) reconstructed Seram but did not display Sumba. Subsequent models by Hall (2001), however, incorporated Sumba as a fragment of Sundaland based on geological criteria, which is consistent with the faunal data presented here. Other areas are more hotly contested, with differing geological interpretations. For instance there are many proposed tectonic models for Timor, which can be tested with the biogeographic model proposed here. The Eocene fossil data favors the model of mixed Sundaland terrains over-thrusting the colliding Austra-

lian plate, as discussed in the many papers of Audley-Charles (1968) and Barber. This model contrasts with those having Timor as a wholly Australian derived fragment, such as that of Chamalaun and Grady (1978), which concluded that "there should be continuity between the stratigraphy of Timor and that of the Sahul Shelf" (p. 107 op.cit); - a summary inconsistent with the data presented here.

THE CHRISTMAS ISLAND EOCENE FAUNA

An obvious omission to the data set was the Eocene of Christmas Island in the Indian Ocean south of Java, on the oceanic plate bordering the Australian plate (Figure 6). This locality is fixed to the northern flank of the Australian Plate and has drifted north towards Java at the same rate. In the Eocene it would have been at equivalent latitudes to the Northwest shelf of Australia and further south than many parts of Papua/PNG. Eocene strata are known from this area from the work of Jones and Chapman (Andrews 1900), who identified *Discocyclina* here. Later work on the older Ter-
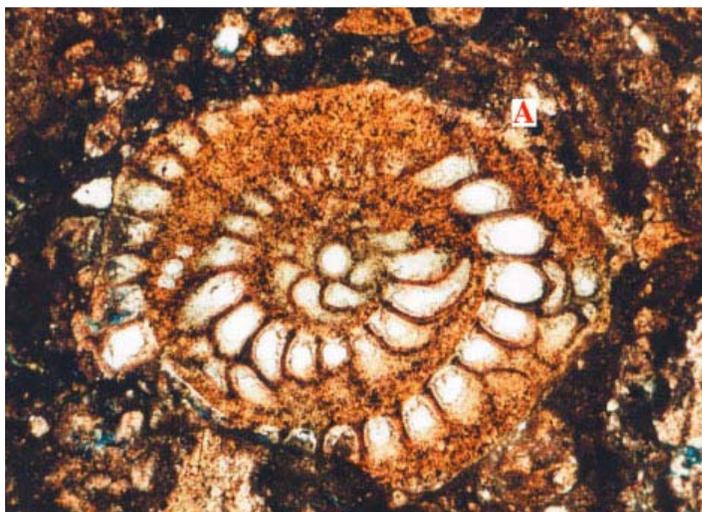
Figure 7. Thin section from yellow limestone. *Grzybowskia jasoni*. The size of the protoconch is 105 ±5 µm, which is smaller than the modal size, possibly because this section is not through the center of the test, particularly on the side in contact with the deuteroconch. (Most "A" generation protoconch chambers are in the range of 150 µm to 200 µm.) In this specimen, there is one post embryonic whorls before the adult stage begins with the acquisition of secondary chamberlets. Just before reaching two whorls, at the point marked "A," the rate of whorl expansion appears to increase, but passes out of the plane of this section. At this point, the secondary chamberlets become more numerous.

Thin section FFC 4B shows the maximum dimension is 1.54 mm.

tiary faunas is limited, so samples were collected for me in November 2001 by J. Jaworski and are the subject of this review.

Summary

The fauna does not vary much from that described by Jones and Chapman, with *Discocyclina* and a large Heterostegine, named here as *Grzybowskia jasoni* dominating all the older Tertiary samples collected. None of the previous workers have described any other Eocene assemblage. A typical view of the whole rock and fauna is shown in Figure 7.

History of Study

Jones and Chapman studied samples collected by Andrews (1900) and reported *Discocyclina* and common large Heterostegines, but equally noted the absence of *Nummulites*. At this time the definitions of the Eocene and Oligocene were not precise, so these early workers assigned a broad Oligocene or Eocene age to the *Discocyclina*-bearing beds. In 1926 Nuttall studied the *Orbitoides* of Christmas Island and established the new species *Discocyclina oceanica* in the Eocene, defined at the same location as the samples studied here, but he did not study the Nummulitacea. In 1965 Ludbrook wrote a short account of the Tertiary foraminifera, in which the oldest limestones of Andrews (called "A" and "B") were grouped as one unit and described as having the same lithologic and faunal composition. The fauna was described as consisting of *Discocyclina oceanica*, "*Heterostegina* sp. cf. *H. saipanensis,*" or sometimes just *H. saipanensis* - a form that had been defined by Cole in 1953 on Saipan Island in the Pacific - with associated *Sphaerogypsina globula*, species of *Pararotalia, Amphistegina*, and rare *Nummulites* [apparently a single occurrence] seen only in a "natural section on one of the samples" from Flying Fish Cove.

Most recently Adams and Belford (1974) studied a large number of samples from Christmas Island, but this work was focused on the Oligo-Miocene limestones, and the occurrence of Eocene was only noted in passing. In the most famous Eocene outcrop at Flying Fish Cove there is a natural geological break between these two limestone groups in the form of a basalt flow that overlies the Eocene, and this basalt is the base of the section Adams and Belford studied. The age of this basalt has been determined by J. Hamilton of CSIRO as

$$K = 0.82 \text{ wt\%}$$
$$\text{Rad. } 40Ar = 4.7116E\text{-}11 \text{ (mol/g)}$$
$$\text{Rad. } 40Ar = 36.05 \text{ (\%)}$$
$$\text{Age} = 32.8 \text{ Ma, analytical error } 0.8 \text{ Ma.}$$

This Early Oligocene age is consistent with its stratigraphic position between Eocene limestone and the lower Te (Late Oligocene) limestone reported by Adams and Belford (1974).

In 2001, a wide range of samples were collected at the Flying Fish Cove site, from both the yellow and the white limestone facies (see Figure 6). Andrews (1900) described this site as "by far the most important exposure of the central core of the island." The limestone here is about 50 ft thick, although the base is not visible. Limestone samples were slabbed and polished to provide a large study area in reflected light, while 21 large format thin sections from different samples provided a total estimated area of about 350 sq cm of thin-sectioned rock. This sample set is thought to give a representative view of the Eocene larger foram fauna at Flying Fish Cove.

Two samples of the white limestone were analysed for whole rock strontium isotopic dating by T. Allan of CSIRO. Results were: $^{87}Sr/^{86}Sr = 0.707630$, 2 sem 0.0016%

0.707683, 2 sem 0.0013%

$^{87}Sr/^{86}Sr$ ratios normalized to $^{86}Sr/^{88}Sr = 0.1194$

$^{87}Sr/^{86}Sr$ ratios normalized to NBS987 $^{87}Sr/^{86}Sr = 0.710235$

Measured NBS987 $^{87}Sr/^{86}Sr = 0.710232$

2 sem - 2 standard errors of the mean (2s/n)

Modern seawater (Mobil) $^{87}Sr/^{86}Sr = 0.709168$

Attempts were made to find some of the other, much smaller Eocene locations reported by Andrews but with no success. The analyses of Jones and Chapman (1900) suggested the fauna of these other areas was similar to that seen at Flying Fish Cove.The results were similar, but are slightly below most published minimum values for Tertiary seawater calibration curves. It is possible that the overlying oceanic basalt has contaminated the limestone. However, the results are within measurement error of a Late Eocene limestone from Java (unpublished, Gamping Barat location, same labs; 0.707637, 2sem 0.0012%). These results are all slightly lower than Middle Eocene bioclasts with excellent preservation from the Nanggulan section on Java (same labs; 0.707722, 2 sem 0.0017%). This additional data is also courtesy of T. Allan and CSIRO, who have observed similar low ratios in the Eocene of PNG. Therefore, it may be that the values measured in Flying Fish Cove do reflect true Sr ratios of the original limestone, and it is the correlation from these ratios to a time scale that needs more attention.

Palaeontology

The fauna recorded in this material is consistent with the summary of Ludbrook (1965). *Discocyclina* and the Heterosteginid form dominate, with frequent *Sphaerogypsina globula* and *Amphistegina*. There is no discernable difference in fauna between the white, slightly porous limestone and the more massive (no visible porosity) yellow-orange limestones, both of which are classified as foraminiferal packstones to wackestones. The matrix in both types of rock is composed of lime mud, fragments of rhodolithic algae and small calcareous foraminifera, brozoan and echinoid debris. The rhodolithic algae appears to be varied, but only rarely does it appear to encrust any bioclasts, and then usually only bryozoan fragments. Only very rare planktonic foraminifera were recorded, and these examples were considered juvenile *Globigerina* forms. Miliolid foraminfera are rare and represented only by small, thin-walled, *Quinqueloculina/*

Triloculina types. Most of the bioclastic debris is less than 2 mm in size, with the exception of the Discocylinids and Heterosteginids. The *Discocyclina oceanica* are about 2 mm in diameter, a criteria used by Nuttall to distinguishing this species from the larger *D. dispansa* Sowerby, to which the Christmas Island forms had originally been assigned by Jones and Chapman. The *Grzybowskia* specimens range as large as 5 mm, and the *Sphaerogypsina globula* to 1.4 mm.

For brevity only the new form *Grzybowskia jasoni* is described here. Flying Fish Cove was the type location for the only other common form *Discocyclina oceanica* Nuttall, and the specimens I saw were entirely consistent with Nuttall's (1926) original detailed notes.

SYSTEMATIC PALEONTOLOGY

Family NUMMULITIDAE de Blainville, 1825
Genus *Grzybowskia* Bieda 1950

Type species: *Grzybowskia multifida* Bieda 1950

Grzybowskia jasoni sp. nov.
not *Heterostegina reticulata* Rütimeyer 1850; Jambor-Kness 1988, pl. 40. *Grzybowskia reticulata* (Rütimeyer); Banner and Hodgkinson, 1991, p. 272.
not *Heterostegina reticulata* Rütimeyer; van der Vlerk 1929, p. 16, figs. 7 and 26.
not *Heterostegina saipanensis* Cole; Ludbrook 1965, p. 288, 291, 293, pl. 22, figs. 4 and 6.

Type specimen: Figure 8 herein. Paratypes in Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, Figure 14, and Figure 15. The sample containing the holotype, and samples and thin sections shown as paratypes, and other paratypic material is stored at the GRDC Museum in Bandung.

Type location: Flying Fish Cove, Christmas Island. Limestone by the road into the cove, below basalt, mostly of light yellow colour, GPS location 105.666680°E, 10.429940°S (estimated accuracy ability).

Derivation of name: At the request of the collector of these samples, John Jaworski, after Jason Jaworski.

Description: Test free, calcitic, planispiral, lenticular, bilaterally symmetrical and involute, with canaliculated periphery. Rapidly expanding whorls, especially in late adult phase, which ultimately produces a thin gerontic flange. Test remains involute throughout (not maturo-evolute). Alar prolongations are well developed and present throughout, although reduced in gerontic stage. The overall
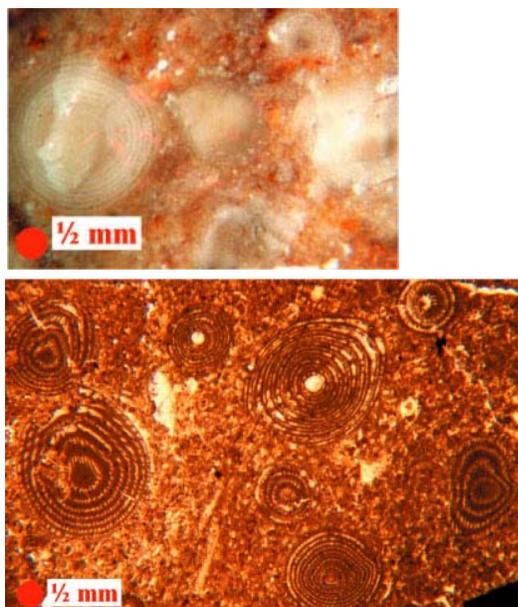
Figure 8. Images of some of the key genera discussed in this report. 8.1. *Lacazinella wichmanni* (Schlumberger 1894), in hand specimen (left) and same sample in thin section to right, from one of the small islands southeast of Misool, near Papua (ex. Irian Jaya). The hand specimen has been wetted, and each white *Lacazinella* is about 2 mm in diameter (same scale as thin section below). 8.2. This limestone is typical of many occurrences of *Lacazinella*, in a low diversity assemblage dominated by this single genus of foraminifera.

Figure 9. Holotype of *Grzybowskia* jasoni polished surface of hand specimen showing development of adult and gerontic stages. Alignment of primary chamberlets of equal height (three of which are marked with black squares) produces a spiral within the adult whorl. In the final, gerontic stage the multiple and irregular chamberlets form a more rapidly expanding rate of growth. Hand specimen number FFC H1. Maximum dimension on this specimen is 3.1 mm. Flying Fish Cove, Christmas Island.

size for adult tests is around three to four mm for the more common A forms, with such a test comprising about four whorls. Axial thickness is about 0.8 to 1.0 mm. The microspheric B forms are only slightly larger than the A generation, the few found being 4 to 5 mm with protoconch diameters between 20 and 30

The *Nummulitic* cord and related canal systems are apparently fine and hard to describe in any detail. A typical Nummulitid intercameral foramen, in a median basal position, is present in all growth stages.

In equatorial sections three stages of growth can be recognized. The first stage lasts about one to two whorls and can be compared with an "operculine" phase in other heterosteginids, although in this involute form is closest to a *Palaeonummulites* test, with simple, radial septa becoming backwards-curved outside the alar prolongation. This stage typically has a maximum size of about 1 mm.

In the adult stage the septa for each instar of growth consist of a radial septum enclosing the alar prolongation, which extends only part way up the outer face of the previous instar. This septum,

Figure 10. Whole rock thin section from yellow limestone showing a number of sections of *Grzybowskia* jasoni roughly parallel to the axis of coiling. The completely involute nature of the tests is visible. The resemblance of the juvenile part of the test to *Palaeonummulites* can be seen, lasting until the increasing height of the whorls forms a flange with slightly concave sides. In the central specimen the gerontic stage is distinguishable by its great whorl height, flat and thinner lateral walls and multiple subdivisions. Thin section FFC 3A. The maximum dimension of the largest (central) test is 4.71 mm. Flying Fish Cove, Christmas Island.
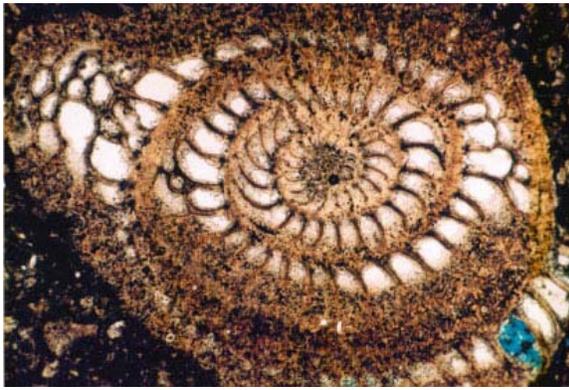
Figure 11. *Grzybowskia jasoni.* Oblique median section through a microspheric specimen. The protoconch is particularly small, at about 15 ±3 μm, but may not be through the centre of the sphere, as indicated by the relatively thick (obliquely sectioned?) enclosing wall. There are about four whorls without subdivison of the chambers [juvenile stage]. This series is followed by a single whorl of the adult stage, with minimal subdivision of the chambers before the onset of the gerontic stage, seen on the left edge here, where the whorl height increases and multiple, apparently irregular, chamberlets occur.
Thin section FFC 1C is the maximum dimension of the largest (central) test is 2.74 mm. Whole rock thin section from yellow limestone, Flying Fish Cove, Christmas Island.

therefore, encloses both new alar prolongations and the lower part of a new chamber lumen. More distally are initially two or three arched septa completing the formation of the instar to the distal limits of the test. In each instar the radial septum enclosing the primary chamberlet continues to grow in a slow, regular manner so that the distal limit where it curves back to terminate against the face of the previous instar produces a spiral alignment positioned slightly above the spiral of the previous whorl (e.g., Figure 8).

The few small chamberlets that extend to the test periphery are irregular in size and shape. The adult stage grades into a gerontic stage but at the transition the size of the test is typically 1.8 mm and three whorls.

The transition from adult to gerontic stages sees a multiplication of the number of small distal chamberlets in the median plane of the test. This increase in the number of rather irregular chamberlets is accompanied by a necessary increase in the spiral height. At the same time, in axial section, the lateral walls can be seen to become thinner than in previous stages (Figure 9). The primary chamberlet maintains a fairly regular size and is still dominantly radial, whereas the smaller, more distal
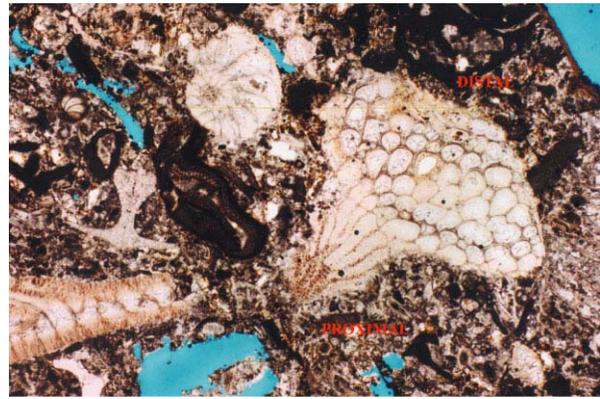
Figure 12. Whole rock thin section from yellow limestone, Flying Fish Cove, showing association with coralline algae and rare small benthic foraminifera. The largest bioclast is a fragment of Grzybowskia jasoni in oblique section of the gerontic stage showing the radial septa extending into the alar prolongations. The distal end of these septa is outside the alar prolongations where the primary chamberlets reach a similar height to form a spiral alignment. More distal to this, the chamberlets are aligned at a high angle, curved backwards and are formed from arched units of irregular shape and size. In this section each instar of growth, with a radial chamberlet and a corresponding row of small chamberlets, can be recognised.
Note that with the highly backwards curved alignment of chamberlets, and associated high rate of whorl size increases, the direction of growth of the test in the gerontic stage tends to become more radial than spiral.
Thin section FFC 1C illustrates the maximum radial dimension of the main specimen; this specimen is 1.54 mm at its widest portion.

Figure 13. Polished surface of the yellow limestone facies from the Flying Fish Cove location, the polishing exaggerating the colour compared to that seen in rough hand specimen. There are numerous specimens of *Grzybowskia jasoni* sp. nov., plus *Discocyclina oceanica* Nuttall near the center of the image. Flying Fish Cove is the type location for *D. oceanica* Nuttall. The image below is 1 cm across.
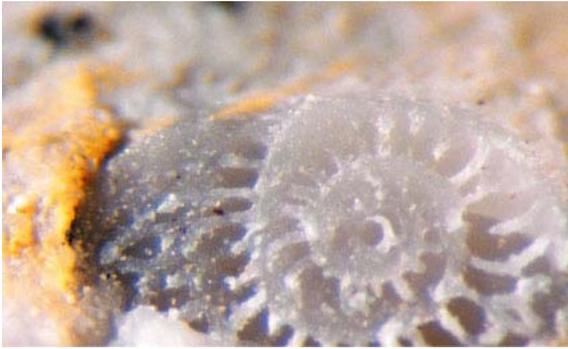
Figure 14. Specimen of *Grzybowskia jasoni* n.sp. in broken surface of hand specimen, in white limestone from the Flying Fish Cove location (See Appendix 3 for locality data). The protoconch is 165 μm in diameter, the deuteroconch is clear, and is followed by just less than two whorls of growth in the form of a *Palaeonummulites*. After this series, the acquisition of the additional chamberlets produces "pseudo-heterostegine" forms for just under one whorl, after which the more numerous additional chamberlets rapidly increases the height of the spire. The image is 3.5 mm in the widest dimension.

Figure 15. Thin section of white limestone facies showing a slightly oblique, slightly off-axial section through *Grzybowskia jasoni* n.sp. and two specimens of the small species *Discocyclina oceanica* Nuttall. The involute nature of the *Grzybowskia* test is clear. The first two whorls are virtually indistinguishable from *Palaeonummulites*, but by the third to fourth whorl the rapidly increasing spire height and increasing numbers of septa distinguish this specimen as an involute heterostegine. Figure is 2.5 mm high.

chamberlets for the same instar are aligned at a very high angle back from the radial. The gerontic marginal flange is therefore a reticulate fan of arched chamberlets, with the common face of each instar now facing far more outwards, and not in the direction of the spial. What happens to the canal system derived from the marginal cord in this gerontic stage has not been determined.

Remarks: This form is placed in the genus *Grzybowskia* because it shares the distinct morphology of the type species, *G. multifeda* Bieda. In particular each adult instar consists of a primary chamberlet, dominantly radial and including both the alar prolongations. The same instar of growth also produces multiple small chamberlets in a strongly backwards-curved alignment, each with rather irregularly arched chamberlet walls. This geometry produces the bifurcations and consequent polygonal chamberlets that distinguish the genus. In the words of Bieda (1950) "*Dans la partie de la spire correspondante a l' état adulte, les bifurcations des cloisons forment des loges secondaires, d'une forme variable*." This contrasts with other members of the Heterostegininae which have a dominant outer septa, clearly defining the instar, and perpendicular internal septula separating the sub-rectangular chamberlets.

The new species illustrated here differs from *G. multifeda* in the form the chamberlets take, and the stage of growth at which they appear. In pl. 3 fig. 1 of Bieda's (1950) original (reproduced as pl. 808 fig 10 in Loeblich and Tappan 1987), as well as

Bieda's pl. 3 figs. 2, 3, 4, 6 and pl. 4 fig. 2, *G. multifeda* shows a preferred alignment of the small chamberlets that implies the outer, more distal one precedes the formation on the next inner one (in other words, the outermost wall is curved, and the next chamberlet wall abuts upon this pre-formed curve). Such a stacking pattern is not seen in the new species described here. In addition the formation of such secondary chamberlets begins in *G. multifeda* almost immediately after the embryonic stage. There may be about two "operculine" or undivided chambers after the embryont, but not lasting more than a third of a whorl. This strongly contrasts with the ontogeny described above, especially the juvenile "operculine" stage lasting about two whorls.

The species illustrated here is the same as that illustrated by Ludbrook (1965, pl. 22, figs. 4 and 6, from the same location in Flying Fish Cove),

but is not conspecific with *H. saipanensis* Cole, which has sub-rectangular chamberlets appearing immediately after the embryonic stages.

The status of *Grzybowskia* has a irregular history due to the original definition of Bieda noting both the distinctive non-rectangular chamberlets (and absence of a primary outer septa) and also the invalid status of *Heterosteginella* Silvestri for involute heterostegines. Thus later workers not only applied the name *Grzybowskia* to forms with polygonal chamberlets, but some also applied the name to specimens with rectangular chamberlets that were involute. However as pointed out by Banner and Hodgkinson (1991), in discussing a broad definition of *Grzybowskia* and related forms, "These polygonal chamberlets are restricted to the Late Eocene. No species of other ages are known to possess them. Similarly, the distinctively broad chamberlets of the later whorls of *Anastegina* also characterize the Late Eocene; nothing like them is known from rocks of any other age. These features alone would justify the taxonomic recognition of these genera as phylogenetically and biostratigraphically distinct, each allows recognition of samples of Late Eocene age. To confuse these genera with the long ranging *Heterostegina (Vlerkina)*, just because all are wholly involute makes no taxonomic or biostratigraphic sense."

Therefore, it can be seen that the heterosteginids with polygonal-irregular chamberlets are a biostratigraphically significant group and the selection of this character to define a genus rather than species appears logical. This degree of identity is supported by the data presented here, which indicates this taxon occupies a specific palaeogeographic setting. The other heterostegines do not appear to have such a restrictive palaeogeography.

The Late Eocene age implied for the Christmas Island limestones (and later Late Eocene implied from text figure 1 of Banner and Hodgkinson 1991) is not yet proven.

Banner and Hodgkinson (1991), citing Herb (1978) and Jambor-Kness (1988), referred the species *H. reticulata* Rütimeyer to the genus *Grzybowskia*. Noting "the pentagonal or hexagonal chamberlets of the early whorls of *G. retculata* (Rütimeyer) ... have been well illustrated by Jambor-Kness 1988 pl. 40)." This species has been recorded in Southeast Asia by van der Vlerk (1929), from the Early Oligocene, Tertiary C, of Northeast Borneo. The illustrations of van der Vlerk clearly show that this taxon is not the species described here, with rectangular chamberlets from a very early ontogentic stage. The original *H. reticulata* Rütimeyer was found in the Late Eocene, as are the specimens of Jambor-Kness, but again nei-

ther the original sketch of Rütimeyer nor the new illustrations of Jambor-Kness show a form like the new species described here.

Finally a note is made regarding a possible morphological link between *G. jasoni* and *Operculina eniwetokensis* Cole, from the Late Eocene of Eniwetok, Guam and other Pacific islands. *Operculina eniwetokensis* has a similar slightly flattened, lenticular, involute test and rate of growth comparable to the juvenile of *G. jasoni*, although the protoconch is half the size. *Operculina eniwetokensis* has a gerontic stage, after two or three whorls, in which a primary chamberlet develops reaching only part way up the apertural face of the previous chamber, together with a few broad and irreguar additional chamberlets (see especially Cole 1957, pl. 232 fig. 23, and Cole 1963, pl. 5 fig. 12). The fragmented, and poorly preserved, nature of the gerontic stage in Cole's figures suggests it is thinner walled, like the gerontic stage of *G. jasoni*. Following the principles of nepionic acceleration seen in many other larger foraminifera, *O. eniwetokensis* could be considered a potential candidate as ancestor to *G. jasoni*. The increase in protoconch size, and concomitant reduction of the juvenile while extending the adult and gerontic stages is a typical ontogenetic pattern seen in phylogenetic reconstructions where better sequences of material are available (e.g., *Cycloclypeus*, *Lepidocyclina*, *Miogypsina*). However, the scarcity of the *Operculina-Grzybowskia* forms, and the short period of time within the Late Eocene suggests it will be hard to find "missing links" to validate this hypothesis. Also it must be noted that *O. eniwetokensis* occurs in the low latitude fauna, whereas this paper has correlated *G. jasoni* with higher latitude assemblages.

PROBLEMATIC EOCENE ASSEMBLAGES

There are two areas where there is confusion over possible overlap between the two exclusive biogeographic markers proposed here. In the Omati to Chimbu Gorge region of Papua New Guinea (Figure 3, area 10 and "O") there is clearly some overlap, although this can be accomodated in the model proposed here, and the absence of *Lacazinella* from known low latitude outcrops remains an independent index of biogeographic origin. However some more work in the Eocene faunas of this region of PNG would be useful, if only to establish the scarcity of the APB fauna here. Bain and Binnekamp (1973) returned to the same area as Crespin's original samples and recorded common *Lacazinella* but noted that "no *Pellatispira* or *Biplanispira* ... occurs". Crespin's

plates, however, appear clear on the matter, and the only confusion is over the extent of overlap.

In eastern Sulawesi there is confusion over sample locations. One interpretation wholly supports the model proposed here, but there is no solid reason to believe this is the correct one. New and accurately located Eocene samples from this area would clarify this issue and may better identify the tectonic suture in this geologically complex area.

Some notes on both these areas are given in Appendix 2.

Understudied faunas

Although not problematic to the model proposed here, a number of understudied Eocene records could be important applications of the APB - *Lacazinella* model in Tertiary plate reconstructions. Possibly of most importance, from a geologic perspective, would be the polymict conglomerate of the Wani beds (from the Tobelo Mts.) in North Buton, where there are records of general Eocene *Nummulites* and *Asterocyclina/Discocyclina* (van Bemmelen 1949 p. 148 and 420). Identification of APB or *Lacazinella* faunas in this area would be important evidence regarding the origin and time of drift of this plate and the adjacent Tukang Besi micro-plate. Van Bemmelen (1949, p. 148) notes that "Several large inliers of Eocene limestone are known from Buton." presumably basing this statement on his main quoted source - the work of Hetzel (1936). However a review of this older work and newer GRDC work suggests the Eocene is not as widespread as van Bemmelen suggests, and the task of finding Eocene pebbles in a polymict conglomerate would be difficult.

Data from the Eocene outcrops on islands along the current collision zone of east Indonesia would help geological reconstructions. The small islands of Raijua and Rotti, described by Verbeek 1908, both have carbonate faunas (cf. van Bemmelen) containing the Middle Eocene marker *Alveolina* but as yet neither the APB or *Lacazinella* fossils. In addition the Eocene larger foram facies on Buru lack any of the biogeographic markers, and more work here would substantiate the data from the adjacent island of Seram.

An Eocene fauna from Ocean Drilling Program (ODP) Leg 133 on the Queensland plateau has been studied by Betzler (personal commun. 1995). This Eocene carbonate contained *Nummulites* and *Discocyclina* but none of the biogeographic markers described here.

As mentioned earlier, some more detailed work on Late Eocene heterostegines may elaborate the geographic range and evolutionary rela-tionships between *Grzybowskia jasoni* Lunt and *Operculina eniwetokensis* Cole. If more records of *G. jasoni* are to be found, the work here predicts a moderately low latitude palaeogeographic range.

SUMMARY

In a large set of data, Eocene outcrops around the Sundaland craton are characterized by the presence of the related genera *Assilina* d'Orbigny 1939, *Pellatispira* Boussac 1906 and *Biplanispira* Umbgrove 1937 [the "APB fauna"]. Another large set of data shows that Eocene limestones on the Australian margin, in south and west Papua New Guinea, west Papua and surrounding islands are characterized by the genus *Lacazinella* Crespin 1962. The record of Crespin (1938) proves that the APB and *Lacazinella* faunas are not totally exclusive of each other. However, the occurrences of the APB fauna on the Australian plate margin are very rare, as Crespin's record is the only one with illustrations. In contrast the *Lacazinella* fauna has not been observed thus far in any plate or micro-plate considered to have been attached to the Sundaland craton or at low latitudes in Eocene times. Therefore, the APB fauna has a distinct preference for low latitude (western Tethys, Sundaland, and Pacific island) locations in the Eocene, but occurs rarely on parts of the Australian margin. More work in the Papua New Guinea (Omati to Chimbu area) and eastern Sulawesi areas should help quantify how often, or how rare, the APB fauna are found to occur in Australian derived locations.

This model was tested by a visit to Christmas Island which lies between the two realms and was not fully documented within such a paleobiogeographic context. In the process, a new Eocene biogeographic cue was identified, as represented by the higher latitude European form *Grzybowskia*. This taxon was at an estimated palaeolatitude comparable to the northern hemisphere records. This specific distribution supports the notion of latitudinal variation in larger foraminiferal assemblages in warm Eocene seas.

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APPENDIX 1.
ASSILINA / PELLATISPIRA / BIPLANISPIRA FAUNA

Sundaland

Pellatispira is common in Burma (Eames in Morley Davies (per ref) 1975) and numerous localities in Sawarak and Kalimantan (**A**) [=the island of Borneo], note only a selection of these Borneo sites are plotted on the summary figure; cf. van Bemmelen (1949) for details. In Sumatra (**B**) sediments of this age are very rare although van Bemmelen reports *Assilina*, with *Discocyclina* and *Nummulites*, from a single site on the Nilam River, N. Aceh (p. 111, op cit.). A paper by Henri Douvillé (1912) on samples from the Eho River in Nias illustrated several types of *Assilina* (e.g., Figure 6.4).

In West Java (**C**) the Bayah area has both *Assilina* and *Pellatispira* (Koolhoven 1933, original sample Blad 14, 356 re-examined for this study), and the sand-rich deposits at Ciletuh contain rare *Assilina* (Verbeek and Fennema 1896, and Duyfjes 1943). Several sites in Central Java (**D**) contain *Assilina*, *Pellatispira,* and *Biplanispira* (Jiwo Hills, Karangsambung, Worowari and Nanggulan – Lunt 1997 and 1998 IPA Field Trip Guidebooks, and van Bemmelen, see also Figure 5.3). Offshore in the eastern East Java Sea (**E**) I have seen *Pellatispira* in cuttings and sidewall core samples from several oil exploration wells. In the West Kangean – 1 and 2 the Late Eocene, miliolid rich, carbonate is without *Lacazinella* (Seimers et al. 1993 and examination of cores at IPA core workshop).

Sulawesi

Van Bemmelen (1949) reports *Pellatispira* from west-central, east-central (i.e. the western part of the eastern arm) and also southern Sulawesi (**F** and **G**, also reported by van Leeuwen 1981, and Wilson and Bosence 1996). Near Tinombo in the "neck" of the northern arm of Sulawesi (**H**) Brouwer (1934, 1947, described in van Bemmelen 1949) reports limestone containing *Assilina*.

The Banda Arc

Caudri (1934) reported and illustrated *Assilina orientalis* Douvillé and several species of *Pellatispira* from southern Sumba (**I**) in the mid Eocene through Oligocene shallow marine Tanah Roong series. In southwestern Timor (**J**) the Dartollu limestones contains a rich *Pellatispira* fauna (van Bemmelen p. 156 and Audley-Charles 1968 and pers. obs.). On Seram (**K**) there are two separate records of *Pellatispira*, from the northern and southern coasts (van Bemmelen 1949).

Papua (ex. Irian Jaya) and iislands

The record of Pellatispira from Halmahera (**L**) is new, but illustrated here (Figure 1), from approximately the same strata examined by Verbeek (1908), who also recorded *Alveolina, Nummulites,* and *Discocyclina* here. Visser and Hermes (1962) noted widespread and thick Eocene limestone from the Bird's Head and Lengguru fold belts, but *Pellatispira* and *Biplanispira* are notably absent. These authors specifically state (p.113 op. cit.) that the only places where these two genera are found are in the Kerkberg Mountains (**M**, around 137E, 220' S) and along the wrench faulting west of this area, near Manokwari = **N**, – see map on next page by GRDC / IJGMP (Irian Jaya Geological Mapping Project) samples south of Manokwari, with contrasting *Lacazinella* faunas on the other side of the Ransiki Fault (Pieters et al. 1985, Ransiki quadrangle report).

Papua New Guinea

There are many Eocene sites in PNG (**O**, and the detailed version of Figure 3) a few with well and not so well documented reports of either *Pellatispira* or *Biplanispira*. The Chimbu limestone yielded the first record of *Biplanispira* east of Borneo, noted as such by Crespin in 1938. Rickwood (1955) noted two locations of micro-fossiliferous Eocene, 8 km apart in the Chimbu area, but with no mention of either *Pellatispira* or *Biplanispira*. Crespin's 1938 paper included excellent illustrations (10 figures on plate 2), so the identity of *Biplanispira* is not in doubt. Carey (1941, in APC, 1961) reported *Pellatispira* from the Er'eri Creek northeast of the Purari River. In the Kapau River pebbles have been found with *Pellatispira* (APC, 1961, p. 55). In the Eocene deposits around Port Moresby, van Bemmelen (p. 185) noted both *Assilina* and *Pellatispira* (without *Lacazinella*).

Pacific Islands

In the Pacific islands *Pellatispira* and/or *Biplanispira* are recorded on New Caledonia (**P**, Grekoff and Guble, 1951), Tonga (**Q**), Fiji (**R**), Saipan (**S**), Bikini (**T**), and Eniwetok (**U**; Cole 1960, 70, 57, 54, and 58, respectively). There are many well-illustrated reports of *Assilina*, *Pellatispira,* and *Biplanispira* in the Philippines (**V**; e.g. Hashimoto 1975).

Lacazinella fauna

North West Shelf of Australia

The Giralia Limestone (1) in outcrop and in the wells Exmouth-1 and Rough Range South-1 contains *Lacazinella* (Chaproniere 1981 and

1984). The type locality of the Giralia Limestone was reported to contain Pellatispira by Chapman and Crespin (1935) but Haig et al. (1997) specifically note that they did not find this genus in their studies. The reports of *Assilina* in the Giralia limestone by Condon (1968) have not yet been verified. There is little other faunal data on the Tertiary limestones of the Northwest Shelf (2) as oil wells often drill through this unit without taking samples. Wells that do recover samples are sometimes examined only in older Tertiary mudstones below the shallow marine limestones. Apthorpe (1988) however, summarises the Eocene Hibernia Fm. of this area as containing monospecific assemblages of Lacazinella wichmanni.

West Papua and surrounding islands

In 1894, Schlumberger formally described the genus *Lacazinella*, - as *Lacazina*, type species *L. wichmanni* - from the 1859 collections of von Rosenberg taken from "Southwest New Guinea" and a few islands in that neighbourhood. Lacazina is the name for *Lacazinella* prior to the 1962 revision of the genus by Irene Crespin.

In 1903, the expedition of Wichmann, the first of four sent by the "Maatschappij ter bevordering van het Natuurkunding Onderzoek der Nederlandsche Koloni'n" (Society for promotion of the scientific investigation of the Dutch Colonies), explored the north coast and the southwest coast of Papua. Foraminiferal limestones that he collected between the island Namatotte and Etna Bay yielded D*iscocyclina* s.l. *Nummulites, Alveolina* and *Lacazinella*, - identified in Rutten 1914; near location 7. The following three expeditions over the next nine years explored the area from the south coast to the Sneeuwgebergte (Snow Mountains) in the interior of southern New Guinea (Hubrecht 1908, and Van Nouhuys 1910). From this work Rutten (1919) described Eocene *Alveolina-Lacazina* limestone collected from the top of the "Wilhelmina summit" (4,750 m, north of 8).

In 1904 an expedition was undertaken on behalf of the Kon. Nederl. Aardr. Genootschap (Royal Netherlands Geographic Society), in which Moerman participated as geologist. He found Eocene limestones east of Etna Bay (Moerman, 1908), in which Verbeek (1908) identified *Lacazinella*.

Military expeditions from 1907 to 1915 sometimes included geologists and, on one of these, Heldring found Eocene limestones boulders in the Noord and Noord West Rivers, described by Martin (1911) who identified *Nummulites, Alveolina* s. str., *Lacazinella* and *Heterostegina*.

Lacazinella is recorded on Misool (5), several locations on the Bird's Head, and elsewhere in western Papua, on the Onin and Kumawa peninsulas and the Lengguru fold belt (Visser and Hermes 1962, and many Irian Jaya Geological Mapping Project reports e.g.: Ransiki (6), Waghete and Kaimana (7). This latter quadrangle report maps a large area of limestone annotated as the *Lacazinella/Discocyclina* facies. The same fauna is recorded many times in wells in these quadrangle reports, which can be verified and expanded by personal observations including ASF-1, ASE-1, TBE-1, Besiri River-1, ASA-1, ASB-1, and South Oeta-1 wells (8). In central Papua, Lacazinella is noted in boulders of Faumai formation at the base of the younger Akimeugah formation in the Otakwa River. In the Enclosure 10 V of Visser and Hermes, the Eocene outcrops are mapped for the west Papuan region. Some areas are marked as open marine/pelagic dominated, including the Onin Peninsula where some *Lacazinella* has been reported, but also several other locations, not detailed in the text of the report, are annotated as Eocene platform or reefal limestones.

Rutten (1936) described *Lacazinella* on the Pisang Islands, sometimes with *Alveolina* and macrospheric *Nummulites* (*N. bagelensis*) indicating a Middle Eocene age. Exploration wells in the area noted in available reports to contain *Lacazinella* include the ASF-1, ASE-1, TBE-1, Besiri River-1, and also the ASA-1, ASB-1, and South Oeta-1 wells (unpublished personal observations).

On Kai Besar (3) *Lacazinella* is reported by Verbeek (1908) and van Bemmelen (1949). Verbeek (op cit. p.171-2) discussed in detail the previous misidentification of *Lacazinella ("Lacazinae")* as *Alveolina* in "Alveolina limestones" from Kai. Bursch (1947), confirmed by Adams (1970), described the Kai Besar fauna occurring with the reticulate *Nummulites* fichteli thus indicating that either *Lacazinella* occurs as young as the basalmost Oligocene, or these usually Oligocene *Nummulites* forms are known from latest Eocene.

In more recent surveys, *Lacazinella* faunas are recorded many times in wells and the quadrangle reports of the GRDC [IJGMP], e.g. Ransiki (6), Waghete and Kaimana (7). Other wells include ASF-1, ASE-1, TBE-1, Besiri River-1 [cf. reports of the IJGMP], and from personal observation in the ASA-1, ASB-1, and South Oeta-1 wells (8). In Papua New Guinea, around OK Tedi (9) Belford [1984] reports Lacazinella. The area marked (10) covers several locations with common *Lacazinella*, but in one instance occurring with rare Biplanispira (See text on APB faunal distribution).

Sulawesi

Koolhoven (1930) reports L. cf. wichmanni from the east arm of Sulawesi (4). *Lacazinella* is reported nearby in the offshore Tiaka-2 and -3 wells offshore eastern Sulawesi (personal observation, cited with permission Union Texas [Tomori] Ltd.).

Papua New Guinea

In the OK Tedi area (9, Telefomin and Tekin areas of Belford 1984) there are *Lacazinella* faunas. They also occur in Pupitau on the east of the Kerabi Valley (APC 1961), as well as at Lake Tebera-Hathor Gorge, I the area of the Pio and Puri rivers, in the Kereru Range, and in the Puri-1, Barikewa-1, Wana-1, Kuru-2, and –3, and Omati-1 wells (as part of a re-worked assemblage in the latter). The area marked (10) covers several locations with common *Lacazinella*, but in one instance occurring with rare Biplanispira –(See text and detail map on the Papuan area).

Eocene carbonate faunas with neither marker recorded

Christmas Island (Circled 1) is described in this report. The small islands of Raijua and Rotti (Circled 2) described by Verbeek (1908) and van Bemmelen (1949) have Eocene carbonate faunas including *Alveolina*. Samples from a polymict conglomerate (Wani beds) from the Tobelo Mts, in North Buton (Circled 3) contain *Nummulites, Asterocyclina / Discocyclina* [van Bemmelen (1949) p. 420]. On the Island of Buru (Circled 4) are at least two locations with Eocene larger forams [Wanner 1907, Henny and Toxopeus 1922]. On Waigeo Island (Circled 5) Brouwer (1924) found a fragment of Eocene limestone in coarse breccias with small *Nummulites*, plus Discocyclina. In Central Irian Jaya (Circled 6), both north and south of the zone of imbricate melange and ophiolites are limestones of Eocene age recorded by Visser and Hermes (1962) with *Nummulites / Discocyclina* assemblages. Finally, ODP Leg 133 on the Queensland plateau (Circled 7), has records of *Nummulites* and *Discocyclina* (Betzler 1995, and Betzler, personal. commun. confirmed no records of APB or *Lacazinella*).

APPENDIX 2.

In Appendix 1 a very few locations are mentioned with single records of marker taxa outside their biogeographic provinces. After checking many other such unsubstantiated and un-illustrated records in archives and oil company samples and finding them to be misidentified, such a few single reports are not considered a concern and in most cases cannot be checked. However, there are some areas with more substantial problems,which can be re-investigated. The following are some notes should these anomalies prove worthy of investigation.

Eastern Sulawesi

van Bemmelen (1949) mentioned some samples with ? *Pellatispira* and *Assilina* in the Unit D of Hopper (1941) as being from the eastern arm of Sulawesi. There is ambiguity whether this fauna is from eastern east Sulawesi, near where Koolhoven (1930) recorded *Lacazinella* cf *wichmani*. (see p.153 of vB) or in the northwest of this arm, near Bungku - Bongka. Some locations of eastern Sulawesi Eocene strata are shown in the map figure 162 on plate 14 of van Bemmelen (1949), but it is not clear which locations have yielded which fossils. In light of the apparently mixed faunas in parts of PNG, it would be palaeontologically and geologically important to establish how the two faunal groups are distributed in the eastern arm of Sulawesi. The presence of *Lacazinella* in this area, however, indicates that some of eastern Sulawesi was derived from the Australian margin, after Eocene times.

Papua New Guinea, the Omati to Chimbu Gorge area

Most of the Eocene records from Papua New Guinea show clear differentiation of *Lacazinella*-only Australian faunas, and APB bearing facies, the latter being clearly part of terrains added later to the modern Papuan island. However there are a number of outcrops and wells with data that do not fit a simple dichotomous model. These sites are all in the area between the Omati Trough and the Chimbu Gorge.

1. Chimbu Gorge

The paper of Crespin (1938) clearly shows *Biplanispira,* and in two figures there are specimens of *Lacazinella* in the same view as *Biplanispira* (plate 2, figs. 15 and 17). This (what?) is the only well-documented case of the two faunal groups co-occurring. As Bain and Binnekamp (1973) and also Rickwood (1955) demonstrated, *Lacazinella* is common in later Eocene rocks of this area and noone has yet to find any more examples of the APB lineage from this area.

2. The Barikewa-1 well

The publication of the APC (1961, p. 50), in discussing the Eocene, states "The upper section of shoal limestone contained abundant *Lacazina, Pellatispira*, and rare *Discocyclina* ..."

3. The Iviri-1 well (APC, drilled 1965, open file report)

A Eocene core in Iviri-1 (core #40) was reported to contain *Biplanispira* and *Pellatispira*. On the composite log this core is described as "*Brown to dark brown, ill sorted, fine to medium grained calcarenite, slightly silty, much impure black argillaceous material, glauconitic, pellets of dark limestone and claystone which are probably reworked Cretaceous sediments, solubility very variable between 40-95%, fossils few but very significan*" Cores 37, 38, 39, and 41 from the same Mendi formation are light grey to brown, without the complex description of core 40 and despite "*numerous fossils*" the key fossils of *Pellatispira* and *Biplanispira* are not recorded in these other cores. A re-examination of the cores would be useful.

4. The Kuru-2 and 3 wells

The publication of the APC (1961, p. 53), in discussing the Eocene, states "The fauna in these bores is characterised by the presence of *Discocyclina* spp., *Biplanispira mirabilis, Spiroclypeus vermicularis* and *Operculinoides* sp. over all but the basal 120 feet. *Lacazinella wichmanni* supplemented this fauna over all but the topmost 60 feet."