Elements of Paleogene Geology of Indonesia – Part 1.
History of Discovery and Biostratigraphy

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ABSTRACT

This introductory paper provides a comprehensive overview of the Paleogene sediments and fossils of Indonesia, synthesizing over 170 years of geological research to guide future stratigraphic studies. While less extensively studied than Neogene sequences due to fewer outcrops, fewer well penetrations, and lower economic hydrocarbon discoveries, Paleogene successions (66–23 Ma) offer critical insights into distinct paleoclimatic and paleotectonic regimes. The paper focuses on the history of discovery, biostratigraphic concepts, and the distinct characteristics of three regional paleotectonic domains (Eurasian, Gondwanan, and SW Pacific) that amalgamated into a complex mosaic of sedimentary basins. This paper discusses first discoveries of Paleogene deposits in Indonesia, Paleogene biostratigraphy and the terrestrial world of Paleogene sequence.

Keywords: *Paleogene, history of discoveries, Paleogene fossils, biostratigraphy*

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INTRODUCTION

This paper introduces the many aspects of Paleogene sediments and fossils of Indonesia, with an emphasis on the history of discoveries and the development of (bio-)stratigraphic concepts. It covers an eclectic range of topics. Ample references should facilitate more in-depth research. One personal goal is to show how much work has already been done over the last 170+ years, which will hopefully guide future researchers to not repeat it but rather build on it. A comprehensive treatise of the Paleogene of Indonesia would have been interesting but would require a much larger volume that also incorporates data on volcanism, collisional and rifting events, etc., which are beyond the scope of this paper.

Paleogene sequences (66-23 Ma) are known from many parts of Indonesia, deposited in different paleogeographic settings and under different tectonic regimes. They tend to be less well studied than Neogene rocks because (a) there are fewer available outcrops and well penetrations, and (b) compared to the prolific Oligocene-Miocene interval, economic hydrocarbon and mineral discoveries are much less frequent in Paleogene rocks.

Paleogene and Neogene sedimentary deposits differ from each other mainly because Paleocene rocks formed during much warmer and more humid paleoclimate, particularly during the times of Eocene thermal maxima. Among the most distinctive Paleogene facies are *Nummulites* limestones, coal deposits, and lacustrine shales.

Paleogene stratigraphic successions across Indonesia reflect deposition in the three main paleotectonic domains, with Eurasian (Tethyan), Gondwanan and SW Pacific origins. These domains amalgamated during multiple Cretaceous and Cenozoic collisions; however, to keep things challenging, parts broke up by rifting and spreading, not necessarily separating along older suture zones. This resulted in a complex mosaic of different Paleogene sedimentary basins or groups of basins, with different tectonic evolutions and sedimentation at different paleolatitudes/paleoclimates.

Some of the key points of this introductory paper on Paleogene deposits and fossils in Indonesia are as follows:

1. Paleocene - early Middle Eocene deposits are virtually unknown in western Indonesia because of the widespread subaerial exposure of the Sundaland Craton, likely controlled by regional 'dynamic topography' preventing the subsidence of the Sundaland Craton. Deposits of this age are known from Eastern Indonesia.

2. Eocene deposits reflect deposition in ice-free, hothouse-greenhouse global paleoclimate, which:

a) affected faunal and floral compositions (absence of corals),
b) Generally reduced clastic sediment supply rates.
c) Subdued eustatic sea level fluctuations, likely affecting cyclicity and sequence stacking patterns.
d) The Eocene was probably also a time of minimal thermal stratification of the oceans, but it is

not clear how this would affect shallow marine biota and sedimentation.

3. The Oligocene started with a major extinction event among tropical larger foraminifera assemblages, reflecting the onset of an ice-house climate, with depositional patterns and biota more similar to the present day.

4. A widespread Oligocene (partial) depositional hiatus is present from Sumatra to Papua and may reflect one or more global eustatic sea level drops, such as those observed by seismic stratigraphers worldwide (P. Vail, etc.).

5. Eocene larger foraminifera assemblages are a useful tool to distinguish between 'Asian' versus 'Australia-New Guinea/Gondwana margin' paleo-positions of terranes during Eocene time.

6. Several poorly dated limestone units in both West and East Indonesia that are widely viewed as of Paleogene age may, in fact, be much older.

Paper 1 of the 'Elements' review includes a brief history of discovery of Paleogene deposits in Indonesia, starting around 1850 in SE Kalimantan and Java. Additional discoveries of Paleogene outcrops followed in Sumatra, the Moluccas and New Guinea, until by the 1920s most of the Paleogene outcrop localities known today (mainly Eocene *Nummulites* limestones) had been located and documented. In Part II, we also discuss the initial problems of age determination of Cenozoic rocks encountered by early workers in the Netherlands Indies (now Indonesia) and highlight the key players that contributed to improved understanding. Cenozoic fossils collected in 'the Indies' were initially interpreted as new and mostly endemic and could not be correlated to European faunas and stages (this is no longer believed to be 100% true, as several species of Eocene molluscs and larger foraminifera have since been found in other parts of the Neotethys belt. Major progress came with the development in 1927 of a micropaleontological zonation based on larger foraminifera known as the 'Far East Letter Classification' of larger foraminifera, by paleontologists of the Geological Survey in Bandung. Part III is a brief review of Paleogene palynology, the principal biostratigraphic and paleoclimate tool in non-marine deposits, as well as the implications of some rare Eocene mammal occurrences.

Paper 2 of this 'Elements' review discusses the characteristic sediments and faunal types during the Paleocene-Eocene hot and humid hothouse/greenhouse climate versus the Oligocene-Recent 'icehouse' time, when the climate was cooler, more variable, and subject to more pronounced glaciation-driven eustatic sea level fluctuations. In low latitudes, average paleotemperatures during the Eocene Climate Optima were estimated to be up to 8-14°C above today's 'normal', and slightly cooler during the Late Eocene greenhouse time. The climate also tends to be more humid. These conditions promoted deposition and preservation of coal beds and lacustrine shales, while shallow marine carbonates typically comprise larger foraminifera packstones and grainstones, instead of mainly coral-bearing reefal or platform limestones of the Late Oligocene-Recent period.

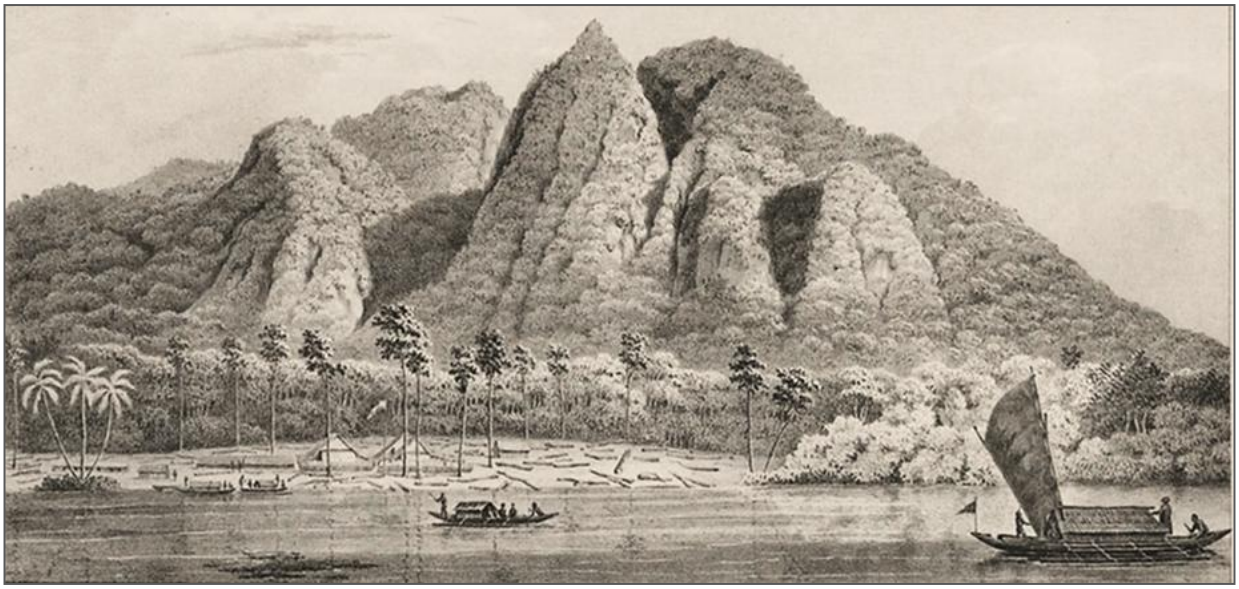


Fig. 1. *Eocene limestones at Lamantjieri, Kaimana Bay (frontal SW Lengguru foldbelt), from a sketch of the Triton Expedition of 1828-1830 (in Muller, 1857. At that time there was no photography. It also shows the start of construction of the short-lived 'Benteng Fort du Bus', the first attempt of a Dutch government presence in New Guinea.*

Paper 3 of this 'Elements' review focuses on Paleogene regional events, including widespread Paleocene and Oligocene hiatuses, Paleogene paleogeographic domains as defined by Paleogene larger foraminifera assemblages and a preliminary grouping of Paleogene tectonostratigraphic successions in 7 or 8 distinct categories. Finally, in Part IX, we discuss the Paleogene ages assigned to two limestone formations in Sumatra and SE Sulawesi that lack diagnostic microfaunas and are located in areas with Permian and/or Triassic carbonate formations.

Some of the history of micropaleontology in Indonesia discussed here was also described in papers by Lunt & Allan (2004) and Lunt (2013) and in the 'Pioneers of Indonesian Geology' volumes by Van Gorsel (2022; which focused on the life and contributions of the pioneering geoscientists in Indonesia. This set of papers contains about 250 references. Many more may be found in the *Bibliography of the geology of Indonesia and surrounding areas,* available online at *www.vangorselslist.com*.

FIRST DISCOVERIES OF PALEOGENE DEPOSITS IN INDONESIA

The first discoveries of Paleogene deposits in Indonesia date back to the 1840s, in SE Kalimantan and Java. In the mid- and late 1800s, age control of Cenozoic rocks was a significant problem for early explorers in the Indonesian region. To address the age problem, many leading European paleontologists of the late 1800s and the early 1900s were engaged in studies of fossils from what was then called the 'Netherlands East Indies.'

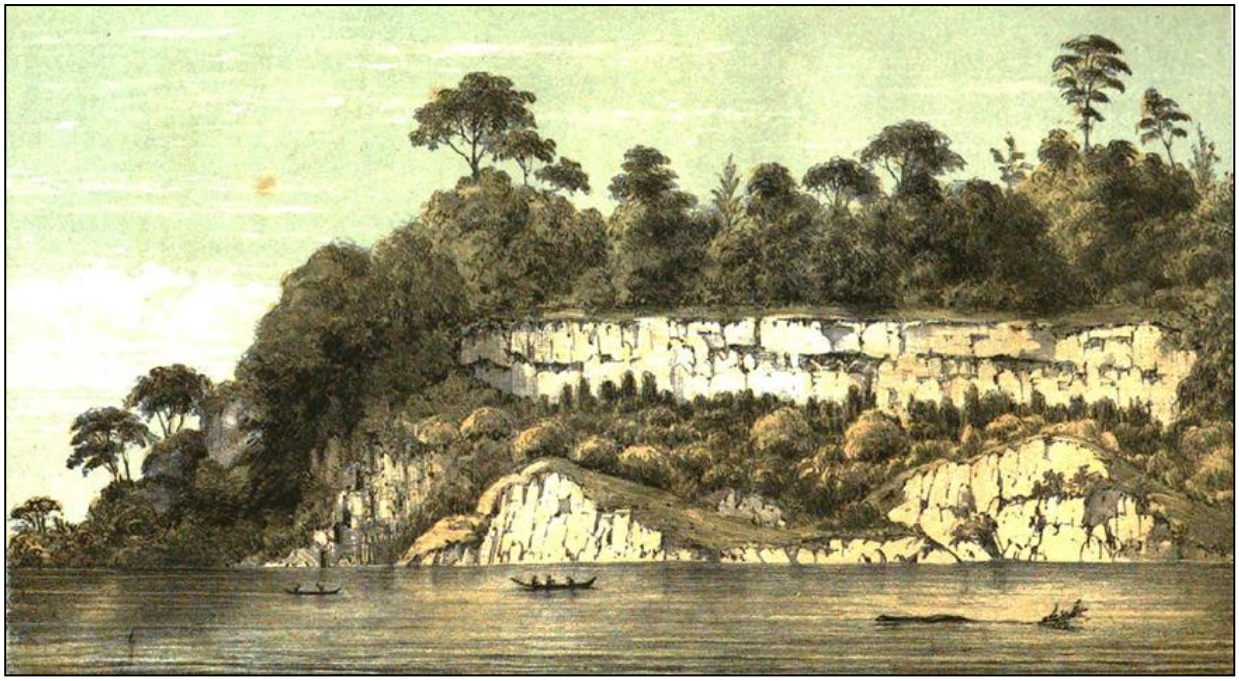


Fig. 2. *Limestone outcrops along the Riam Kawa, a tributary of the Barito River in SE Kalimantan. (not clear if this particular outcrop was Eocene Nummulites limestone or the latest Oligocene Berai Formation (lithograph after a sketch by Schwaner's illustrator H. von Gaffron in the mid-1840s (in Schwaner, 1854).*

First observations of Paleogene deposits: Muller, Schwaner and Junghuhn (1840s).

The very first samplings of Paleogene rocks in outcrop in Indonesia came from three 'Members' (naturalist explorers) of the *Natuurkundige Commissie voor Nederlands-Indie* (Natural History Commission for the Netherlands Indies), organized and funded by the Natural History Museum (now Naturalis), in Leiden, the Netherlands. All were German and 'naturalists', with broad interests in all natural sciences, but were not specialists in geology, which had yet been recognized as a branch of science.

The 'first touch' of Eocene limestones was probably by Salomon Muller, while seconded to the government-sponsored Triton Expedition to the eastern parts of the colony in 1828-1830 (Fig. 1). Muller was probably not aware of the Paleogene age of these limestones at that time. This formation in the frontal parts of the Lengguru foldbelt was re-sampled by Wichmann in 1903, and larger foraminifera *Lacazinella wichmanni*, *Alveolina (Fasciolites) wichmanni,* and *Discocyclina* were described from these samples by Rutten (1914).

The first actual recognition of likely Paleogene-age rocks in Indonesia came from two Members of the *Commissie*, Carl A. Schwaner and Franz Junghuhn. Schwaner reported fossiliferous limestone outcrops in the Riam Kawa district in the Barito Basin of SE Borneo (Fig. 2), which he compared to the '*Nummuliticum*' of Europe (during the 1800s, the name *Nummuliticum or Nummulitique*

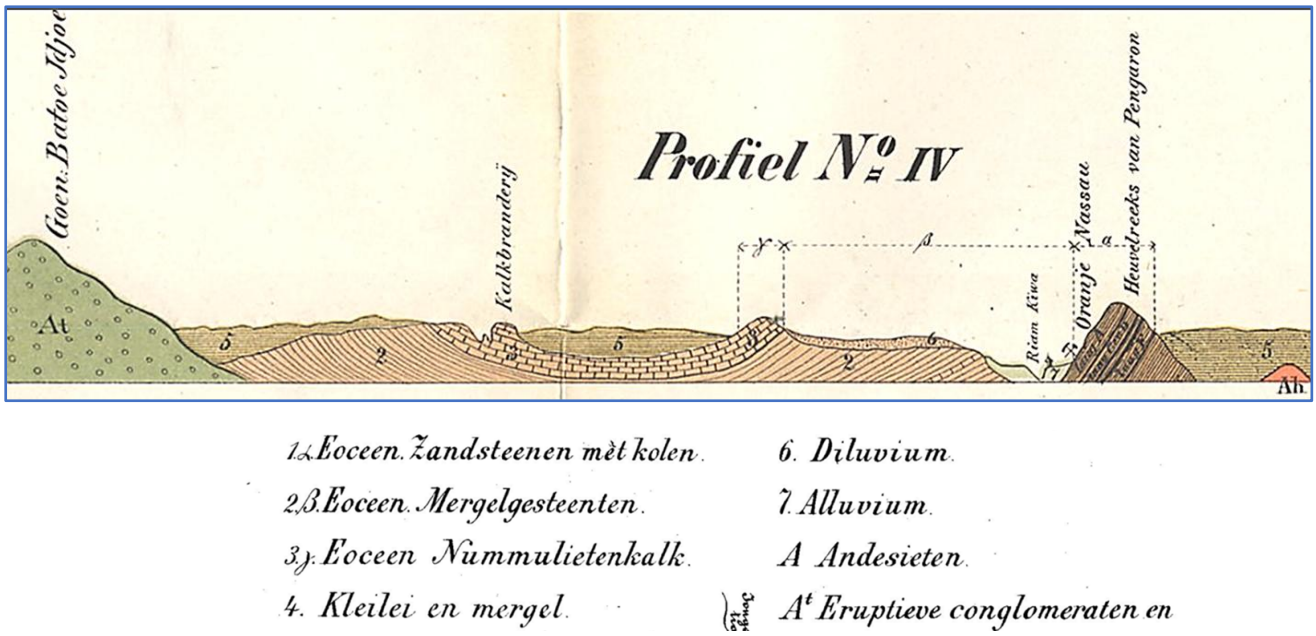


Fig. 3. *Cross-section across the area of the Oranje Nassau coal mine at Pengaron in the SE margin of the Barito Basin, SE Kalimantan (Verbeek, 1875), showing (1) Eocene sandstones and coals, (2) Eocene marls and (3) Eocene Nummulites limestone*

represented formations from the geological time period with common *Nummulites* fossils, i.e. the era now known as Paleo- Eocene). However, due to Schwaner's untimely death from malaria in Batavia in 1851, further details of this discovery were never published. Schwaner's suggestion was later proven to be correct by R.D.M. Verbeek (1871), who became the first to describe and illustrate typical Eocene larger foraminifera from Indonesia, including four species of *Nummulites*, including *N. pengaronensis* n.sp. and four species of '*Orbitoides'* (now called *Discocyclina).* (see also below)

The third 'discovery' came from the well-known Java explorer Franz Junghuhn during his epic geological and botanical work on Java in the 1840s (without the benefit of any (micro-) paleontological support). On page 313 of the second edition of his famous Java volumes, Junghuhn (1853-1854) mentioned 'larger nummulites' in limestone hills near Tanglar, East of Tjigangsa, but these were never illustrated or properly verified.

Soon hereafter, it was correctly suggested that the 'East Indies Archipelago' may have been an eastern continuation of the vanished Tethys Ocean, which stretched from the Mediterranean area, through the Middle East, the southern Himalayas, and into SE Asia.

Pioneering contributions of Verbeek in Borneo, Sumatra and Java, 1868-1901

R.D.M. (Rogier) Verbeek was one the early mining engineers of the *Dienst van het Mijnwezen* (Geological Survey) and undoubtedly the most consequential geologist in advancing the knowledge of geology of the Indonesian region. He graduated in 1866 from the Mining Department of the *Technische Hogeschool* in Delft, the Netherlands, under the

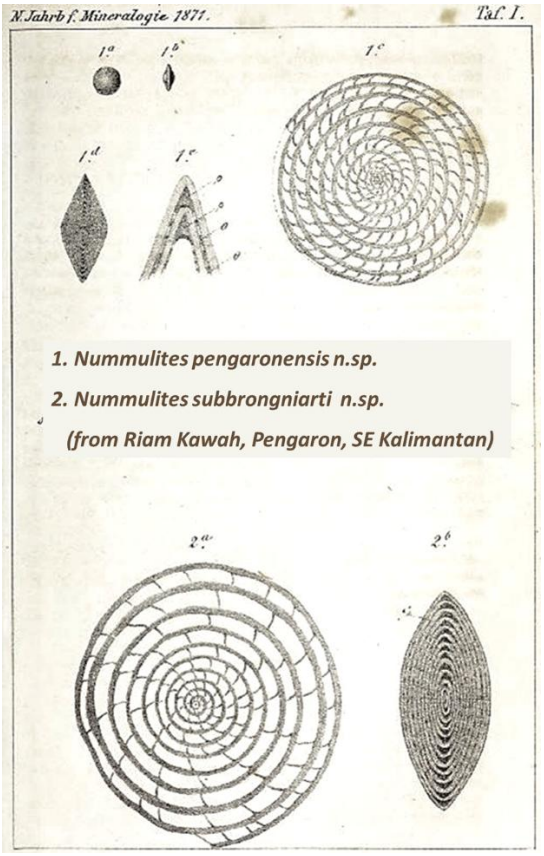


Fig. 4. *The first formal description and illustration of Nummulites from SE Asia (SE Kalimantan; Verbeek, 1871).*

supervision of Prof. H. Vogelsang. Verbeek is known as a world-class regional geologist, for his 'unrelenting' geological mapping work during over more than thirty years during late 1800s in many parts of Indonesia, as well as his milestone work on the 1883 eruption of Krakatau volcano.

In the context of Paleogene, Verbeek was instrumental in developing the first stratigraphies of SE Kalimantan (Barito basin), West Sumatra (Ombilin basin) and most of Java in the late 1800s. Between the late 1870s and the 1890s, Verbeek continued his pioneering work on the occurrences of Eocene carbonates and coal-bearing beds, first in West Sumatra and later across all of Java (Verbeek and Fennema, 1896). His final opus was on the results of his 9-month Moluccas Islands expedition in 1899 (Verbeek (1908).

Probably out of necessity, Verbeek also developed a strong interest in the paleontology of larger foraminifera, as he correctly assumed that these might be the most useful Fossil Group to crack the problem of age determination of Cenozoic sedimentary deposits. Between 1876 and 1896, Verbeek published numerous contributions to the knowledge of Paleogene deposits in the Barito Basin, West Sumatra, all of Java, and across the Moluccas. New Eocene larger foraminifera species described by Verbeek (1871-1892) include species from SE Borneo in 1871 (*Nummulites pengaronensis*), Java in 1891 (*Nummulites javanus, N. nanggoelan1, N. bagelensis* and *Alveolina javana)* and Timor in 1908 (*Alveolina timorense*).

Due to the lack of paleontological expertise at that time in the Netherlands Indies and in the Netherlands, Verbeek solicited help from the top European paleontologists for Paleogene and older macrofossils, who at that time were mainly based in Germany, France, and the U.K. These included Karl Von Fritsch of the University of Halle in Germany, who described Eocene echinoids, corals and larger foraminifera (*Orbitoides* = *Discocyclina*) from Verbeek's *Nummulites* limestone near Pengaron in SE Kalimantan. Reclusive German paleontologist Oskar Boettger from the Senckenberg Museum in Frankfurt, described Verbeek's mollusc collections from various localities in West and South Sumatra (Boettger,1880).

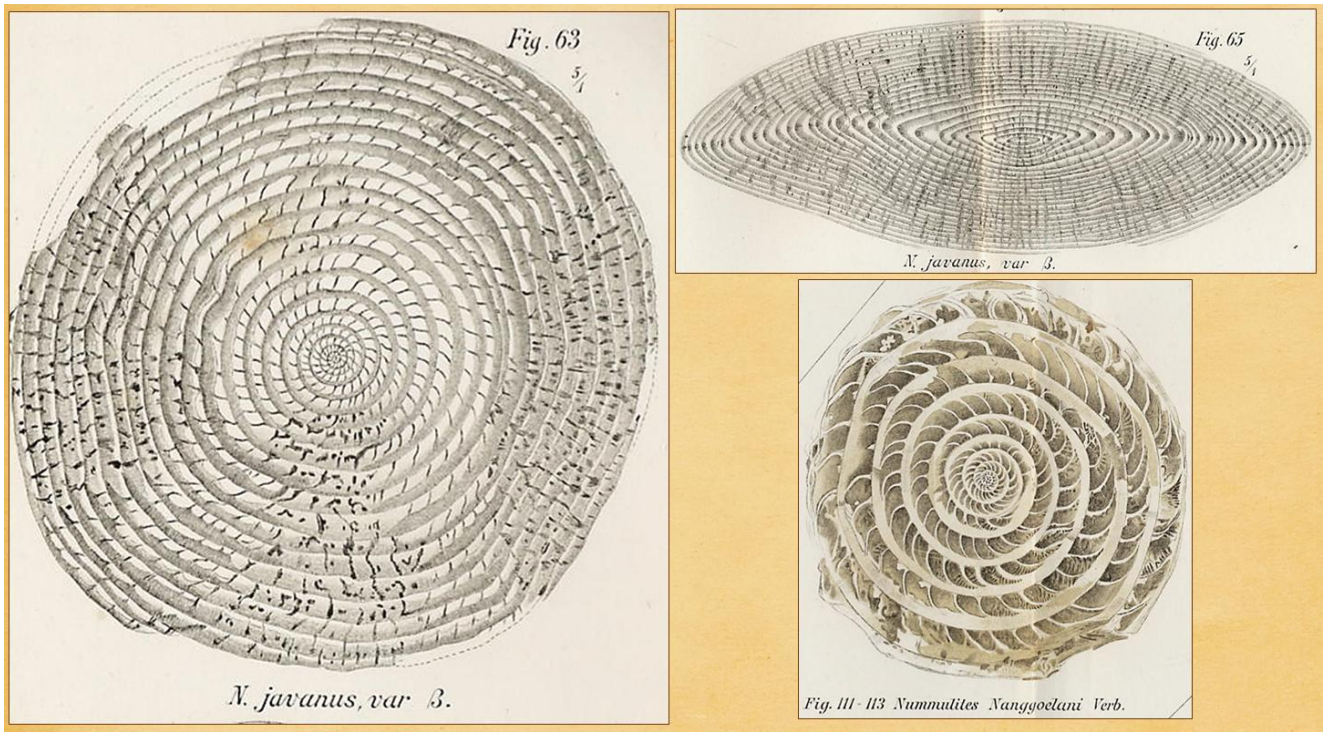


Fig. 5. *Two Middle Eocene Nummulites species from Central Java were first described by Verbeek (1891): Nummulites javanus and N. nanggoelani (reproduced in Verbeek and Fennema, 1896).*

Age of Paleogene outcrops in the Ombilin Basin, West Sumatra

The British pharmacist and leading foraminifera expert in the mid- and late 1800s, H. B. Brady (1835-1891), assisted Verbeek with the identification of Late Paleozoic and Tertiary foraminifera from Sumatra (Brady, 1975). Unfortunately, Brady (1875) misidentified larger foraminifera from a limestone bank overlying the important Sawahlunto coal-bearing formation in the Ombilin Basin in West Sumatra, which became a source of confusion in Verbeek's classic work on the Ombilin Basin. The bank contained 'millions' of orbitoidal larger foraminifera but no *Nummulites*. The forams were identified by Brady as *Orbitoides papyracea*. a species now classified in the genus *Discocyclina,* signifying a Paleocene-Eocene age.

This then led Verbeek to conclude that the underlying commercial coal deposits were of Eocene age, very much like the stratigraphy he was familiar with in SE Kalimantan and SW Java. However, already Verbeek (1891?), Verbeek and Fennema (1896) and Newton and Holland (1899) all realized that Brady's 'Eocene' *Discocyclina* from the Padang Highlands were actually species of *Lepidocyclina (Eulepidina)* (re-described as *Lepidocyclina verbeeki* n.sp. and *L. angulosa* by Newton and Holland 1899; see also Douville, 1912, p. 257). This sub-genus represents a Late Oligocene- Early Miocene (Td-Lower Te) age (hence the absence of *Nummulites*). Although most workers still view the underlying Sawahlunto Formation coal measures as Middle-Late

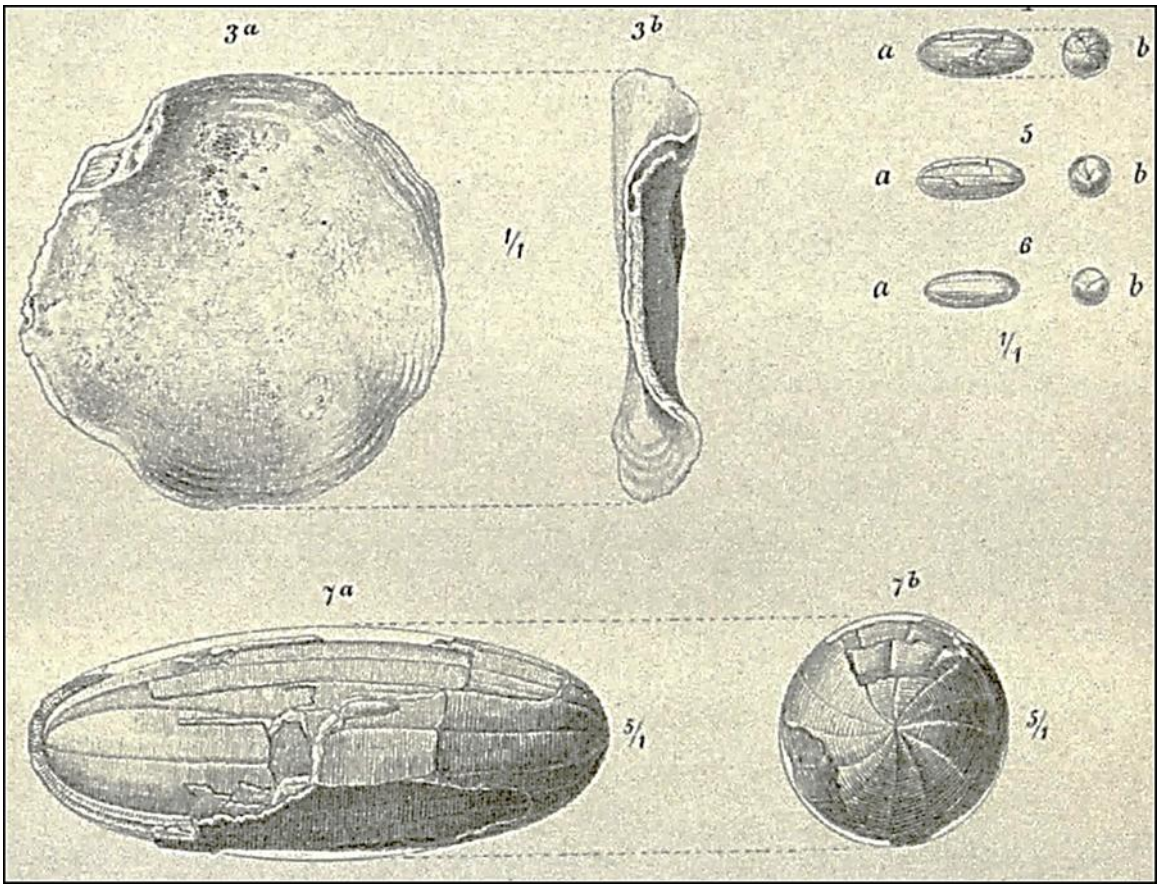


Fig. 6. *'Orbitoides' (= Discocyclina) and Alveolina (also called Fasciolites) javana n.sp., from Bagelen, Central Java (the first Eocene Alveolina described from Java) (Verbeek, 1891).*

Eocene in age, which makes sense from a paleoclimate perspective, some may still doubt whether it is of Eocene age or younger.

Discoveries of Paleocene outcrops outside Sundaland

New discoveries of Paleogene (mainly Eocene) occurrences outside the more familiar areas of Java, Sumatra and Borneo soon followed. New Paleogene localities in Eastern Indonesia and New Guinea were first recognized by European explorers, such as A. Wichmann, J. Wanner, G. Boehm, H.A. Brouwer, E. Abendanon, and others. By the 1920s, most of the outcrop localities of Eocene *Nummulites* limestones known from Indonesia today had already been located and documented.

Key early discoveries of Eocene larger foraminifera limestone in East Indonesia and western New Guinea include:

- 1883- Timor, Eocene *Nummulites* limestone, first described by K. Martin (1883);
- 1889- Roti island, investigated by Wichmann (1889), Verbeek (1899), Wanner (1910) and Brouwer (1915.

With intensely folded Permian-Eocene sediments; Eocene with large *Nummulites, Discocyclina* described by Brouwer (1921) and Douville (1923);

- 1892- Kai Besar: K. Martin first discovered Eocene limestones with the genus *Lacazina* (= *Lacazinella*) from Kai Besar Island (Martin, 1903), described by Verbeek (1908) and Douville (1923) as *Lacazinella*. Also, with *Discocyclina, Nummulites* and *Alveolina*;
- 1892- Seram: K. Martin observations on the presence of *Nummulites* limestones on Seram and Buru (Martin 1903, F. Weber 1926);
- 1894- western New Guinea: Eocene limestones from Triton Bay, sampled by A. Wichmann in 1894? larger foraminifera include *Lacazina (= Lacazinella) wichmanni* n.sp (Schlumberger 1894);
- 1900- Misool- south coast. G. Boehm sampled Eocene *Alveolina* Limestone (Boehm, 1910);
- 1903- New Guinea Expedition, samples collected off Triton Bay by A. Wichmann, with foraminifera *Lacazina (Lacazinella) wichmanni, Alveolina wichmanni* n.sp., *Nummulites* and *Discocyclina* (Rutten, 1914);
- 1904- West Buru: J. Wanner discovered rare Eocene limestones near Fogi, with *Nummulites, Discocyclina*, alveolinids and reworked Cretaceous carbonate clasts (Wanner, 1907, 1923);

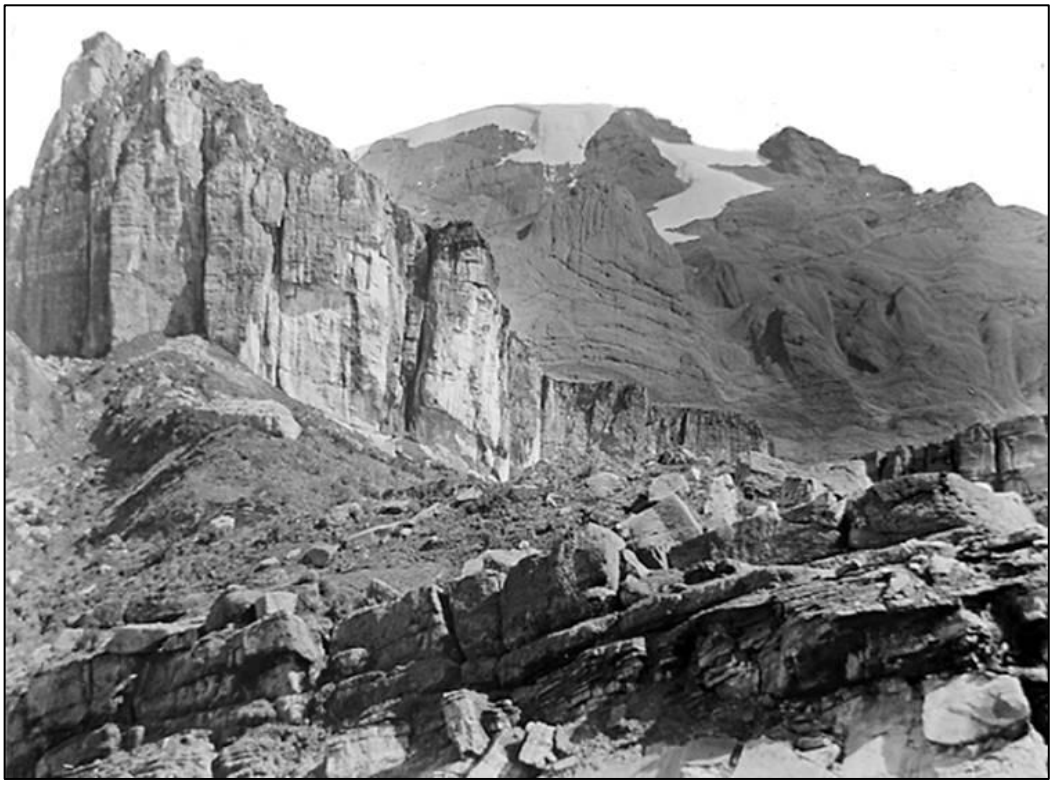


Fig. 7. *The 4750m high Wilhelmina Peak (renamed as Puncak Trikora) in the Central Range of New Guinea is composed of Eocene limestone with Lacazinella wichmanni, Alveolina wichmanni and small Nummulites (Rutten, 1919; photo P.F. Hubrecht, 1913).*

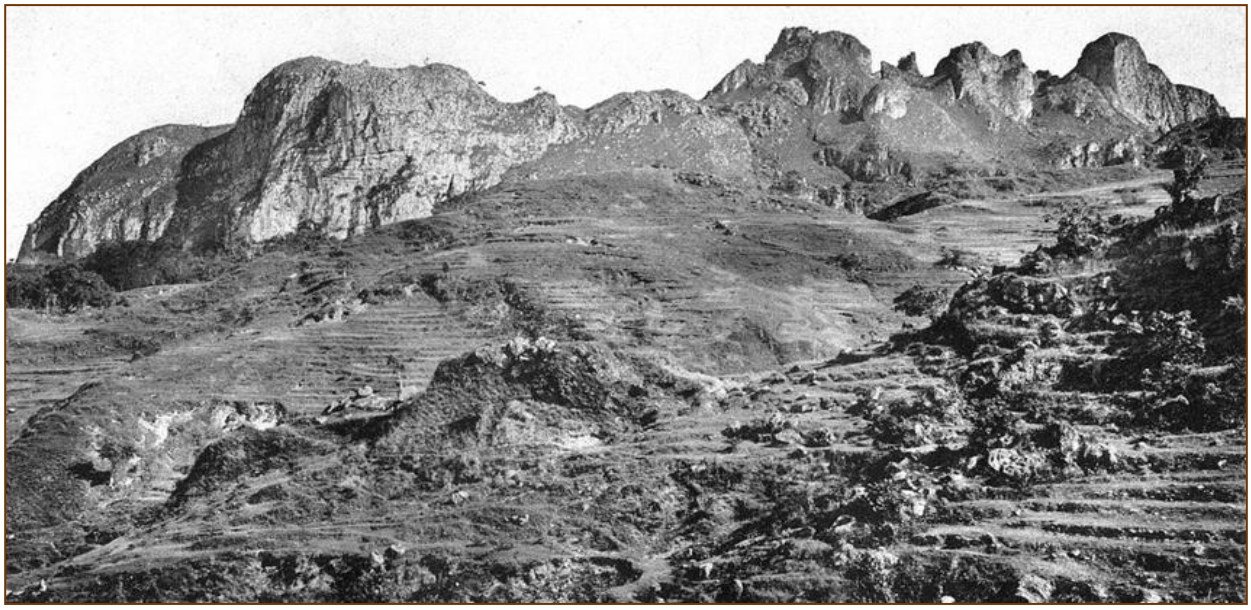


Fig. 8. *Massive late Middle Eocene limestone with Nummulites-Assilina at Makale in Toraja Lands, Central Sulawesi (photo from Van Waterschoot van der Gracht,1915)*

- 1905- East Arm of Sulawesi: J. Wanner collected Eocene limestones with *Alveolina, Discocyclina* and *Nummulites*, deemed 'reminiscent of *Alveolina* Limestone of Misool' (Wanner, 1910);
- 1909- Central Sulawesi: Eocene *Nummulites* limestones were sampled in Central and West Sulawesi during the 1909-1910 *Midden Celebes Expeditie* by E.C. Abendanon;
- 1910- Sumba: Eocene *Discocyclin*a in samples collected by H. Witkamp in 1910, with foraminifera described by Rutten, 1912); Eocene *Nummulites-Pellatispira* faunas described in more detail by C.M.B. Caudri (1934), from samples collected by Kemmerling
- 1910-1912- Timor: Eocene *Nummulites- Alveolina- Orbitolites-Pellatispira* (Ta-Tb) limestones collected during the Timor expeditions of 1910-1912 by G. Molengraaff, J. Wanner and H.A. Brouwer. Larger forams were described by Henrici (1934);
- 1913- New Guinea Central Range expedition: Eocene *Lacazinella-Alveolina* limestones sampled by Hubrecht in 1913, foraminifera described by L. Rutten (1919) (Fig. 7);
- 1913- West-Central Sulawesi Toraja Land: late Middle Miocene *Nummulites-Assilina* limestone, sampled by Van Waterschoot van der Gracht and described by Rutten (1915). (Figs. 8 & 9).
- 1915- Halmahera: samples collected by H. Brouwer in 1915, larger foraminifera described by Douville (1923);
- 1915- Seram and New Guinea: surveyed by H.A. Brouwer around 1915;
- 1917-1919- Seram expedition by L. Rutten; *Discocyclina, Nummulites, Alveolina* and *Pellatispira* described by Germeraad (1946);

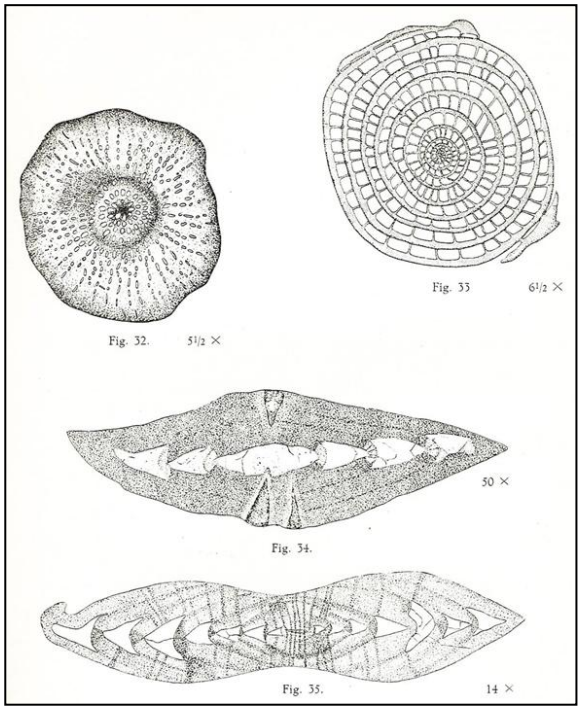


Fig. 9. *Middle Eocene (Ta3) Nummulites and Assilina from Toraja Lands, Central Sulawesi (L. Rutten, in Van Waterschoot van der Gracht, 1915).*

- 1918- Papua New Guinea, pebbles in Fly River, derived from the central foldbelt, with Alveolina wichmanni, Lacazinella wichmanni and Discocyclina (Newton, 1918);
- 1929- Central Sulawesi H.A. Brouwer Celebes expedition, with Middle and Late Eocene larger foram assemblages described by Van der Vlerk and Dozy (1934);
- 1936-Pisang Islands West of Misool (West Papua): collected by Van Straelen in 1929, Rutten (1936) described *Nummulites bagelensis*, *Lacazinella wichmanni, Alveolina, Discocyclina).*

PALEOGENE BIOSTRATIGRAPHY

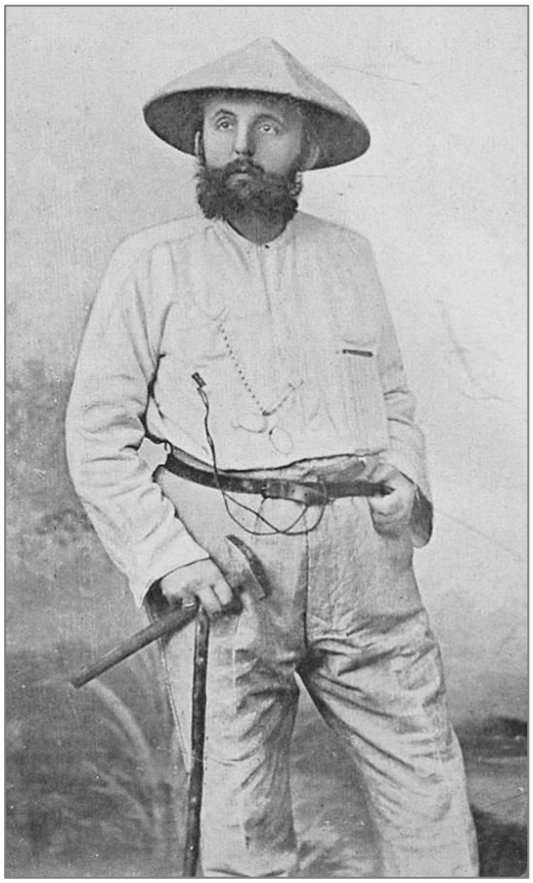
As noted above, age control of Cenozoic rocks was a problem for early geological explorers in the Indonesian region in the 1800s- the early 1900s, and there were no expert paleontological specialists in the Netherlands to consult.

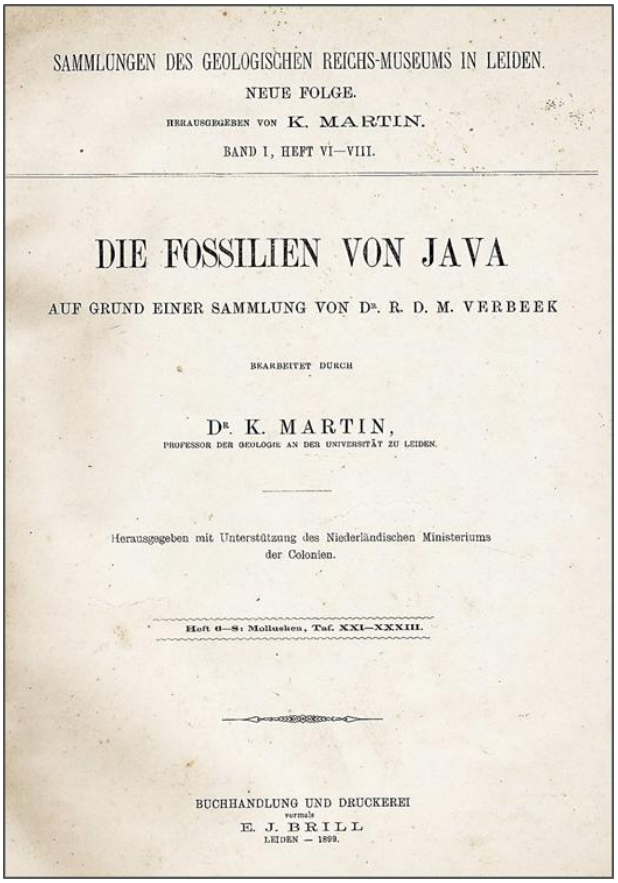
Karl Martin, and the "Percentage of living species method"

The first 'expert paleontologist' who dedicated much of his career to fossils from the Netherlands Indies was German-educated Karl Martin, who was the first professor of geology and paleontology at the University of Leiden and Director of the Geological Museum in 1877-1922. Most of his research was on Cenozoic molluscs in the collections of the Leiden Museum, which had been sent there by F. Junghuhn and other members of the Natural History Commission and by R. Verbeek and other mining engineers from the Bureau of Mines of the Netherlands Indies.

Later in his career, Martin conducted his own two expeditions to the Netherlands Indies, the first to the Moluccas in 1891-1892 (Seram, Buru, Ambon, and other islands), where he did pioneering geological survey work (Martin, 1903), and a second expedition to Java in 1910, primarily to systematically re-sample its classic fossil localities.

Martin described hundreds of new species of Cenozoic molluscs from Java between 1879 and 1932., which earned him the nicknames of 'Father of the Paleontology of the Netherlands Indies' and 'The Linnaeus of Java'. Martin argued that most of the Cenozoic mollusc species in Indonesia were endemic and new to science, In his papers. However, later studies, like on Late Eocene molluscs of Nanggulan in Central Java, suggested that




SAMMLUNGEN DES GEOLOGISCHEN REICHS-MUSEUMS IN LEIDEN.

NEUE FOLGE.

HERAUSGEGEBEN VON K. MARTIN.

BAND I, HEFT VI—VIII.

DIE FOSSILIEN VON JAVA

AUF GRUND EINER SAMMLUNG VON Dr. R. D. M. VERBEEK

BEARBEITET DURCH

Dr. K. MARTIN,

PROFESSOR DER GEOLOGIE AN DER UNIVERSITÄT ZU LEIDEN.

Herausgegeben mit Unterstützung des Niederländischen Ministeriums der Colonien.

Heft 6—8: Mollusken, Taf. XXI—XXXIII.

BUCHHANDLUNG UND DRUCKEREI
vormals
E. J. BRILL
LEIDEN — 1899.

Fig. 10. *Left: Prof. Karl Martin during his expedition to the Moluccas in 1892 (from Escher, 1931). Right: One of the many volumes produced by Martin on the fossils of Java (Martin 1891, descriptions of Java fossils collected by R.D.M. Verbeek)*

many of Martin's Paleogene species were actually younger synonyms of southern European species of the same age, and were therefore not as endemic as suggested by Martin (Piccoli and Savazzi, 1983). Paleogene larger foraminifera of Java have also many elements in common with the western Tethys. While 'Indo-Pacific' provincialism is probably real for Neogene species, this may be less pronounced in the Paleogene before the final closure of the Neotethys seaway.

The endemic nature of Java's Cenozoic molluscs, in Martin's experience, made it impossible to correlate with the known European/ Mediterranean faunas. Therefore, in order to attempt to determine relative ages of mollusc assemblages from Java, Martin resorted to relative age determinations by applying the 'Lyellian' method of percentages of living species. During Pliocene time, the majority of mollusc species were found to correspond to living species. Percentages gradually decreased with time, until Eocene mollusc assemblages contained no species that are still living today (Fig. 11).

Unfortunately, Martin's percentage method did not last long. It proved to be a cumbersome and not very precise method, which (1) required an advanced level of taxonomic expertise (about 2000 Cenozoic

Percentages of living species of Java fossil molluscs (Martin, 1913):	
- Pliocene:	41-75 %
- Late Miocene:	30 %
- Middle Miocene (Nyalindung):	21 %
- E-M Miocene (Rembang Beds):	15 %
- Eocene (Nanggulan Beds):	0 %

Fig. 11. *Percentages of living mollusc species in Tertiary formations of Java (Martin, 1913).*

mollusc species had been distinguished for Indonesia (Van der Vlerk, 1931), and (2) it assumes that Recent mollusc faunas had been adequately inventoried. It was obviously too difficult a method for widespread usage, and paleontological dating soon shifted towards the use of much less diverse and easier-to-collect larger foraminifera assemblages.

Interestingly, Umbgrove (1946) developed a similar percentage scheme for Cenozoic corals, showing before Early Miocene time there are no species that are still living today. (Fig. 12). The percentage numbers for corals appear to decrease with time at a similar, possibly slightly slower rate than for molluscs (K. Martin work).

	Species Still Living (Per Cent)
Pleistocene to Recent	70–100
Pliocene (Tertiary *h*)	50– 70
Miocene, Tertiary *g**	30– 50
Miocene, Tertiary *f*	10– 30
Miocene, Tertiary *e*	0(?)– 10
Oligocene (Tertiary *c* and *d*	0–few
Eocene (Tertiary *a* and *b*)	0

Fig. 12. *Umbgrove (1946), Table II, showing percentages of living coral species through time, distilled from Umbgrove's experience with Cenozoic and modern corals in Indonesia.*

Larger foraminifera to the rescue: Early practitioners in Indonesia

Age determinations in the Cenozoic deposits of Indonesia quickly gravitated towards the use of larger foraminifera (not the redundant 'Larger Benthic Foraminifera'), because they tend to be more abundant and easier to collect and there are far fewer genera. Unfortunately, they are found only in shallow marine carbonates or gravitational debris derived from them, so for the longest time dating of clastic sediments and volcanics in the 'Indies' remained difficult.

Today, larger foraminifera continue to be the primary tool for dating Mesozoic-Cenozoic limestones (for open marine deposits planktonic foraminifera and calcareous nannofossils have proven superior biostratigraphic tools since the 1960s, while palynology is the tool of choice for samples from non-marine and marginal marine clastic deposits.

Leading pioneers in the early 1900s in the field of larger foraminifera in Indonesia and paving the way for the 1927 'Letter



Fig. 13. *Three pioneers of larger foraminifera from the Netherlands Indies in the early 1900s. From left to right: Charles Schlumberger (Paris), J. Henri, F. Douvillé (Paris) and Louis M.R. Rutten (Java, Balikpapan, and later a professor in Utrecht).*

Zonation', were French micropaleontologists Henri Douvillé and Charles Schlumberger, while Karl Martin in Leiden and micropaleontologists from Italy (Provale, 1908-1909, Osimo, 1908) and others also contributed.

H. Douvillé in 1905 and 1912, working on foraminifera from SE Kalimantan and South Java, already noted the Middle Late Eocene character of the *Nummulites-Discocyclina* assemblages, and the likely Early Miocene (Aquitanian- Burdigalian) age of overlying *Lepidocyclina*-rich faunas.

The foreign expert skills on larger foraminifera were soon adopted and expanded by Dutch geologists in Indonesia, initially by geologist Rogier Verbeek (1871- Borneo, 1891-Java, etc.), and followed in 1911-1936 by Louis Rutten, who was employed as a petroleum geologist of the *Sirius* Petroleum company (1910-1917), based in East Kalimantan and Java. He later became an acclaimed expert on the regional geology of the Netherlands Indies and a Professor of Geology in Utrecht from 1921 to1946. Remarkably, he also developed and

* 1912: Eocene- Miocene foraminifera from Sumba Island
* 1914: Foraminifera from the 1903 northern Netherlands New Guinea Expedition (Wichmann samples)
* 1915: Eocene foraminifera from Pulau Laut, SE Kalimantan
* 1916: Eocene foraminifera from NE Kalimantan- Tidung Lands (incl. first Pellatispira (called Calcarina))
* 1919: Eocene foraminifera from Alveolina-Lacazina limestone samples from the Wilhelmina Peak in the Central Range of West Papua.
* 1925 Eocene and Miocene foraminifera from the Birds Head, West Papua (incl. Lacazinella)
* 1926: Oligocene-Miocene foraminifera from Berau, NE Kalimantan
* 1936: Eocene foraminifera from in Alveolina-Lacazinella limestone from Pisang Islands, West Papua

Fig. 14. *Listing of key papers on Paleogene larger foraminifera by L. Rutten.*

maintained a personal interest in larger foraminifera and their potential for age dating. Rutten published 26 micropaleontological papers between 1911 and 1936 (Fig. 14).

Larger foraminifera: Bandung as Center of Excellence, 1920s-1930s

In 1922 Isaak M. van der Vlerk arrived at the *Dienst van het Mijnwezen* (Bureau of Mines/Geological Survey), at that time still located in Batavia, and became the first official resident-micropaleontologist in the country. This was the start of two decades of excellence in SE Asian larger foraminifera research in Indonesia. Under the guidance of Dr. August Tobler, Van der Vlerk had studied Tertiary larger foraminifera from Miocene limestones in Sumbawa Island at the University of Basel, Switzerland, from 1918 to1920. These studies became the foundation for his doctorate thesis under Prof. Karl Martin in Leiden in 1922.

In 1924, offices of the *Dienst van het Mijnwezen* moved from Batavia to Bandung. The new office complex now included an official "*Paleontologisch Laboratorium*", as part of the new Geological Museum. Staff at the Paleontological Laboratory expanded with the arrival of J. Umbgrove in 1926, followed by Heinrich Gerth in 1928 and Tan Sin Hok in 1929, respectively. The Bandung Paleontological Laboratory was at the forefront of expertise in Tertiary larger foraminifera in the 1920s-1930s.

Decades of earlier paleontological studies of larger foraminifera in the Indonesian region culminated in the establishment of

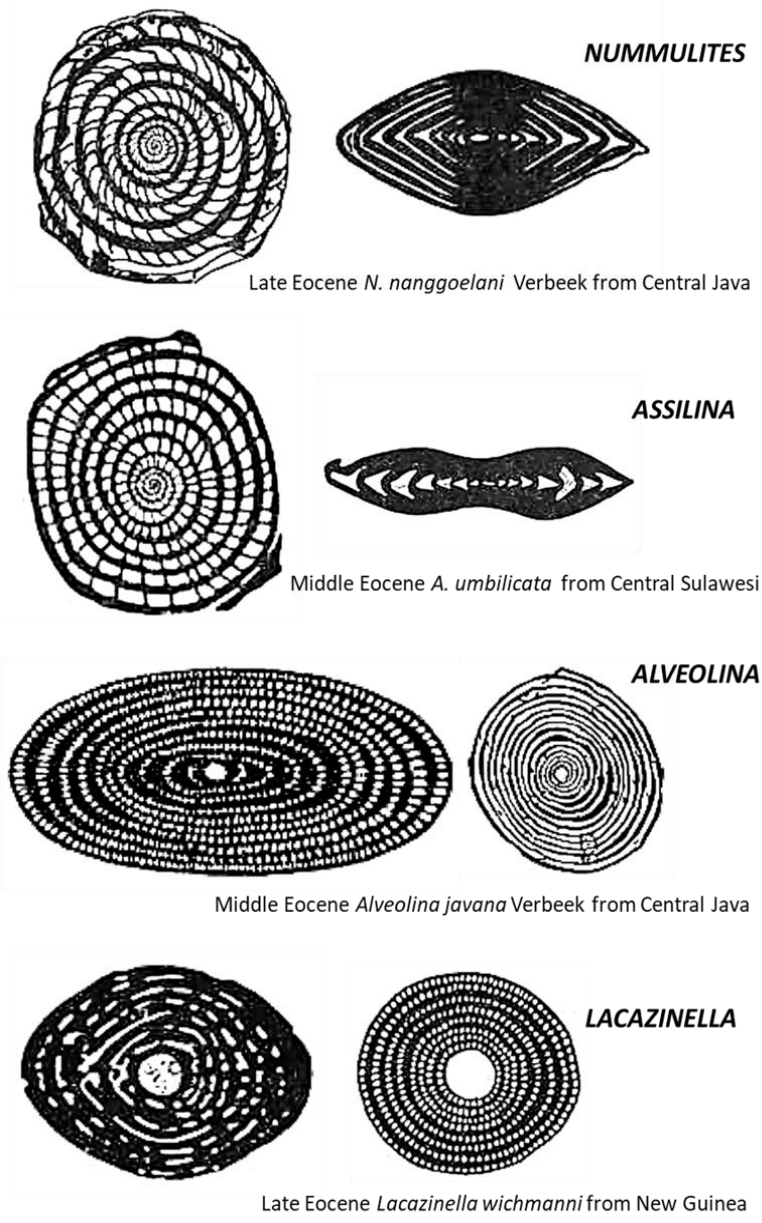


Fig. 15. *Horizontal and vertical (or longitudinal and axial) sections of key Eocene Larger foraminifera (from Rutten, 1927).*

the 'Far East Letter Classification' in 1927, a zonal subdivision of the Eocene-Miocene, based on the first appearance

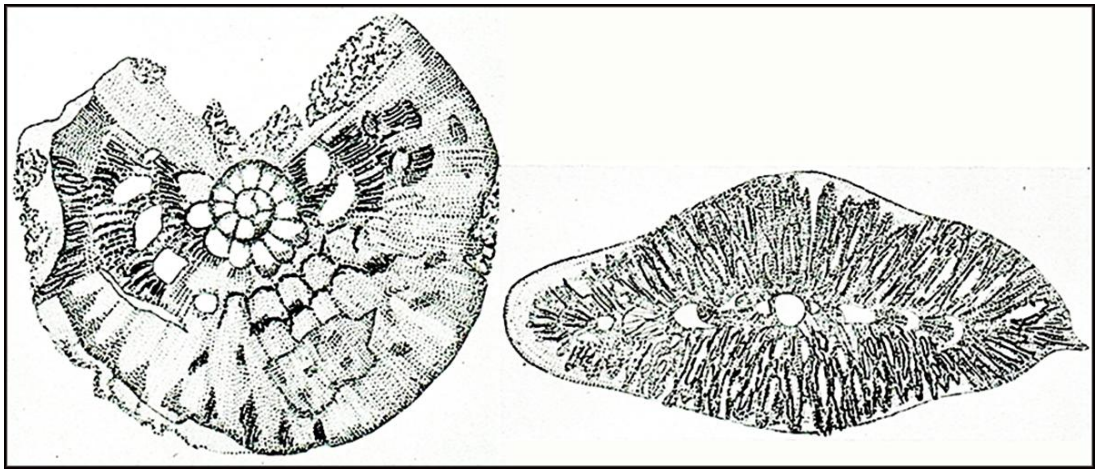


Fig. 16. *Horizontal and vertical sections of Late Eocene Pellatispira sp. from the 'Tidung Lands' in NE Kalimantan (Rutten, 1916).*

and extinction levels of larger foraminifera (Fig. 20). These larger foraminifera zonation, with subsequent updates, remains the most useful tool for age dating of Cenozoic shallow marine carbonates in Indonesia.

The practical advantage of the Letter Zonation was that is based on stratigraphic ranges of a limited number of larger foraminifera genera, many of which can be identified in the field by geologists with limited training and a hand lens (Van der Vlerk & Dickerson, 1927). It does not require specialist knowledge of the often-messy species-level taxonomy of larger foraminifera, where every little morphological variety has been honored with a new name.

A first revision of the Letter Classification soon followed, by Leupold & Van der Vlerk (1931), who added stages (zones) Tg and Th (for 'post-*Lepidocyclina* and Tg-Th; latest Miocene-Recent), subdivided Tf into 3 zones, Te into 5 zones, Ta into 2 zones. These updates were largely driven by new data from the fossiliferous outcrop sections in the NE and E Borneo geological mapping areas of Swiss *Mijnbouw* geologist, Wolfgang Leupold.

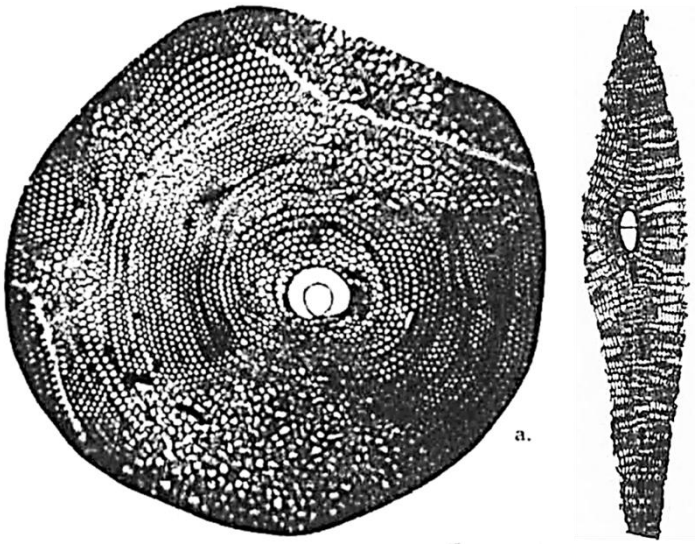


Fig. 17. *Horizontal and vertical sections of Eocene Discocyclina dispansa from NE Kalimantan (Van der Vlerk, 1929).*



Fig. 18. *Personnel of the Paleontological Laboratory in Bandung in the late 1920. The upper left is I.M. van der Vlerk, upper right J.H.F. Umbgrove (Van Gorsel 2022; photo courtesy of Geological Museum, Bandung).*

Additional 'classic' monographs on Paleogene larger foraminifera from Indonesia followed, most of them under the guidance of I.M. van der Vlerk after his return to Leiden, starting with J.H.F. Umbgrove (1928) on the genus *Pellatispira* ,and several other Leiden University doctoral theses: *Spiroclypeus* by W.F. Krijnen (1931), *Fasciolites*/alveolinids of Java and parts of Eastern Indonesia by Bakx (1932), Nummulitidae from Java by Doornink (1932), and a key work by on Eocene and Miocene larger foraminifera of Sumba by Caudri (1934).

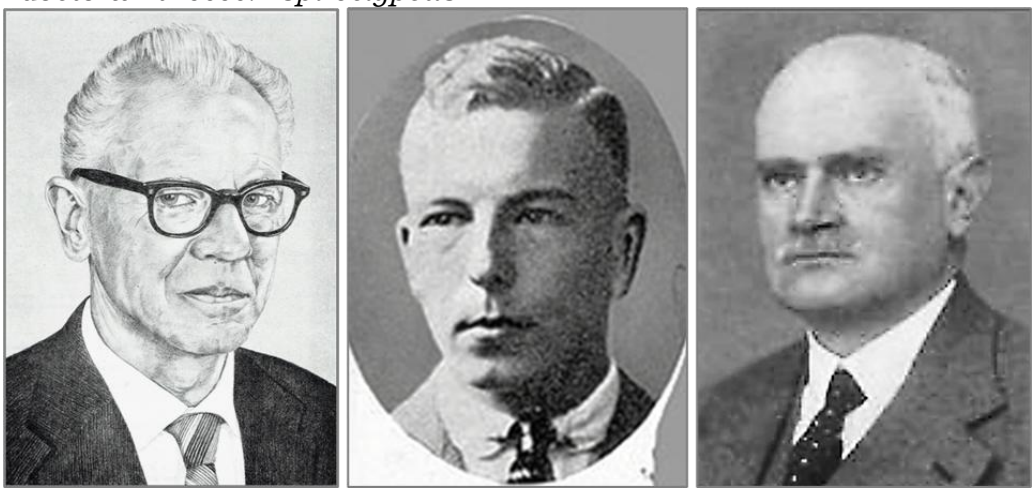


Fig. 19. *Personnel of the Paleontological Laboratory in Bandung in the late 1920s. From left to right I.M. van der Vlerk, J. Umbgrove and H, Gerth.*



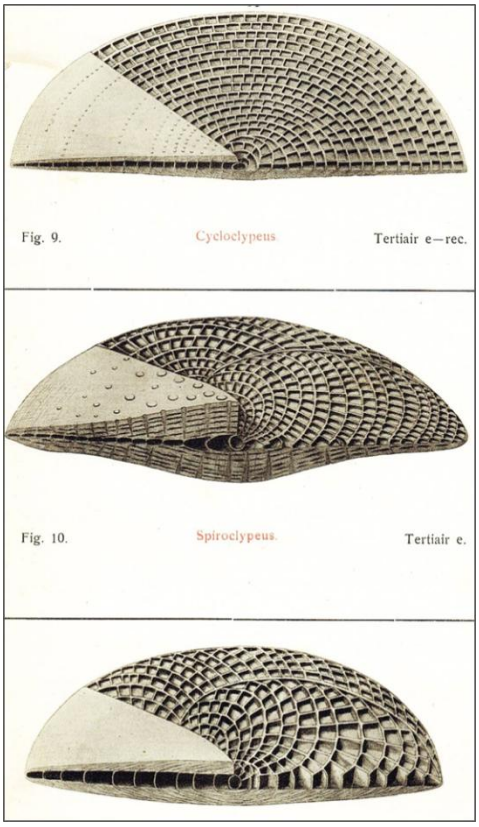


Fig. 20. Left: *The 'pocket guide' to the genera of Tertiary larger foraminifera of the Netherlands East Indies (Van der Vlerk and Umbgrove, 1927). Right: Elegant 3D models of Cycloclypeus, Spiroclypeus, and Heterostegina from this manual.*

Larger foraminifera: Times of refinement, 1930s-1970s

By 1930, Van der Vlerk, Umbgrove, and Gerth had all returned to the Netherlands, and the studies of larger foraminifera in Bandung became the sole responsibility of Tan Sin Hok. Tan was only the second Indonesian native to graduate with a doctorate in mining engineering from the *Technische Hogeschool* Delft, in 1927, with a thesis on a paleontological subject supervised by Prof. H.A. Brouwer.

Through the 1930s, Tan Sin Hok continued to expand on Van der Vlerk's and others' studies and the collections of Indonesian larger foraminifera in Bandung, publishing some 30 papers in the 1930s. He became famous for his pioneering studies on evolution in Oligocene-Miocene lineages, including (1) *Heterostegina* to *Cycloclypeus* (1932), (2) *Neorotalia* to *Miogypsinoides* to *Miogypsina* (1936-1937), (3) *Lepidocyclina* groups and embryonic evolution (1936), and (4) *Heterostegina borneensis* to *Spiroclypeus* (1937), etc. Some of these lineages were elegantly portrayed in Lunt and Allan (2014) and Lunt & Luan (2022).

Except for his work on Oligocene early *Cycloclypeus*, Tan's contributions to the Paleogene (bio-)stratigraphy of Indonesia

were relatively limited, probably partly because the relatively unsophisticated Paleogene larger foraminifera genera showed few or no remarkable evolutionary trends. Tan did describe two new Late Eocene taxa from the Upper Kutai Basin, a primitive *Lepidocyclina (Polylepidina)* (1936) and *Spiroclypeus vermicularis* (1937). Both genera were previously thought to be restricted to the Late Oligocene-Miocene.

Tan's paleontological work came to a virtual halt with the outbreak of World War II in 1940, and the *Dienst van den Mijnbouw* of the Netherlands Indies re-focused from geoscience to evaluating domestic coal, oil and minerals prospects. Tan now did field surveys in Java and South Sumatra. Tan was arrested and interned in Japanese camps on Java in 1943-1945. He survived the camps but was murdered in Bandung soon afterwards, in late 1945 (see also Munasri & Van Gorsel, 2014).

After Tan's untimely death, his work on the evolution of larger foraminifera remained internationally acclaimed for decades, primarily in academic programs in the Netherlands in the 1950s-1970s, in Leiden (Van der Vlerk), Utrecht (C.W. Drooger) and Amsterdam (H.J.

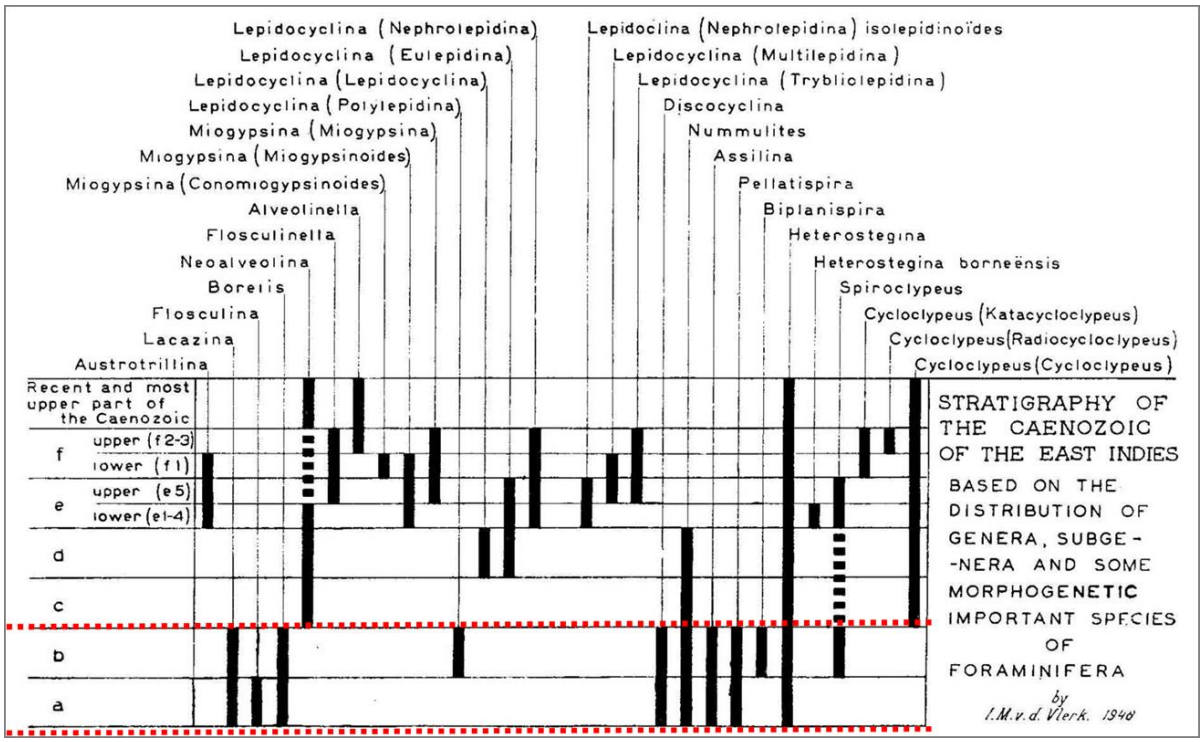


Fig. 21. *A 1948 version of the 1927 'East Indies Letter Classification of the Cenozoic', showing ranges of key larger foraminifera genera (Van der Vlerk (1948. The upper dashed red line between Tb and Tc highlights the global extinction event at the Eocene-Oligocene boundary, also known "La Grande Coupure'. The lower dashed line is a placeholder for the 'LFT", an earlier larger foram turnover event at the Paleocene-Eocene boundary (no deposits of Paleocene- early Middle Eocene were known from Indonesia at that time; Zone Ta as depicted here is now called Ta3, Middle Eocene).*



Fig. 22. *Left: Tan Sin Hok at work at the Paleontological Laboratory of the Dienst van den Mijnbouw in Bandung in the 1930s (photo from Tan family, Amsterdam). Middle: Swiss micropaleontologist Willi A. Mohler (photo from his 1943 Japanese-issued Bandung ID Card (courtesy E. Migliore). Right: C.G. Adams from the British Museum of Natural History.*

MacGillavry), but this type of work was no longer pursued in Indonesia.

Swiss micropaleontologist W.A. Mohler worked for BPM-Shell in Balikpapan in 1938-1942 and in 1946-1949. As a Swiss 'neutral' national, he was not imprisoned during the Japanese occupation. With BPM gone and most Dutch staff interned, he was asked by the Japanese authorities to work in Bandung to work as micropaleontologist at the Geological Survey from 1943-1945. During this time, he was the only paleontologist, who had access to the larger foraminifera collections of Van der Vlerk, Tan Sin Hok, etc., and became very familiar with the material. Back in Switzerland in 1946 for recuperation after the Japanese occupation, Mohler published an elegant 'pocket manual' of Eocene- Recent index genera of larger foraminifera of Indonesia. Instead of the 3D models of Van der Vlerk and Umbgrove (1927), Mohler used photographs of oriented thin sections (Fig. 23) and expressed the hope that these images would be used for training of field geologists, so they could identify larger foram genera and determine likely ages of rocks in real time while investigating outcrops. This never materialized to this day.

Since Indonesian Independence, local expertise in larger foraminifera taxonomy and its application to Cenozoic carbonate biostratigraphy has almost become a 'lost art' in Indonesia, even among recognized carbonate sedimentology specialists. However, this may be changing now, as testified by the works of Diana Rahmawati at UGM (this symposium).

Not only has there been the loss of expertise, but also the loss of collective memory of the heydays before World War II. For instance, the Introduction to a recent Bandung thesis on larger

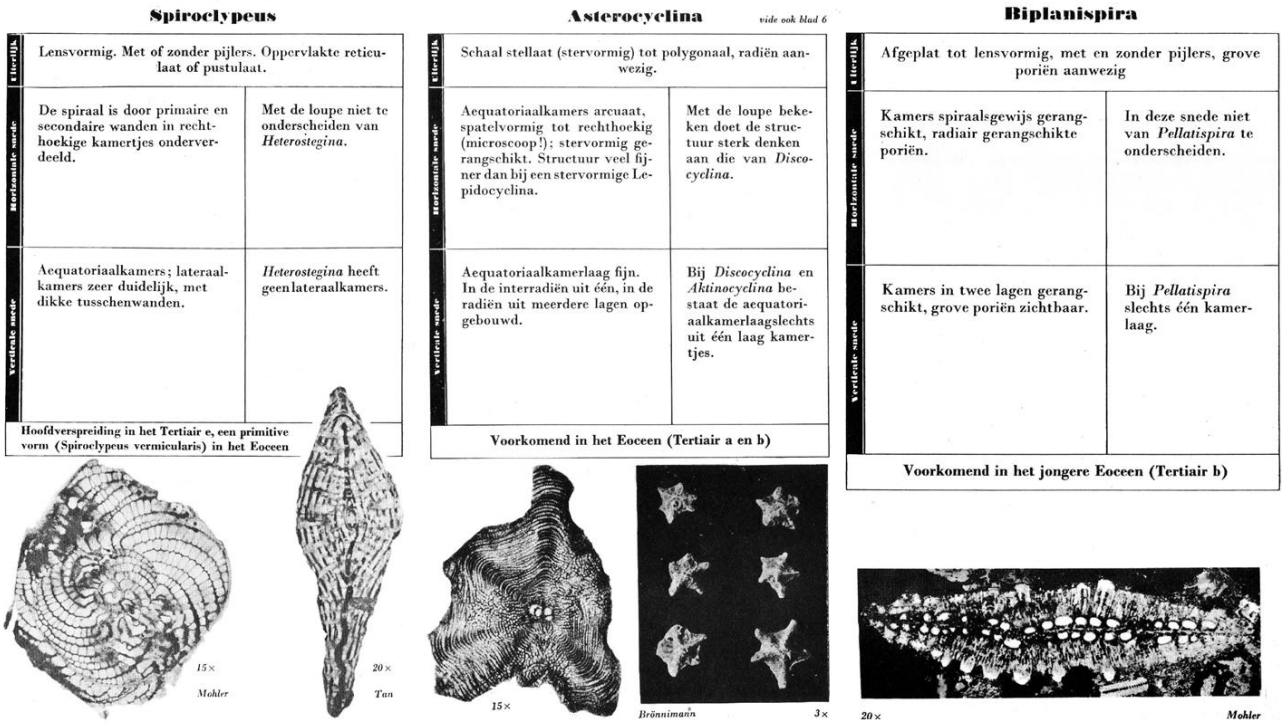


Fig. 23. *Example pages with Spiroclypeus, Asterocyclina, and Biplanispira from the 'Manual for the determination of larger foraminifera of the Netherlands East Indies' (Mohler, 1946).*

foraminifera contained the rather remarkable sentence: "In the Java region, there have been no published studies on the evolution of the Miogypsinidae family". In reality, the evolution of the Oligo-Miocene Miogypsinidae larger foraminifera lineages had been documented in great detail before, in Bandung, by Tan Sin Hok in 1936-1939.

The most significant update of the Far East Letter Stages zonation (especially for the Paleogene) came in 1970 from C.G. Adams, a micropaleontologist at the British Museum (Natural History) in London. Adams was the leading authority on Cenozoic larger foraminifera in SE Asia during the 1960s-1970s. His expertise in these fossils was acquired mainly from years of identifying foraminifera in outcrop samples from Sarawak and Brunei, collected by the *Geological Survey Department of the British Territories in Borneo* in Kuching, and from his own fieldwork on the now classic North Borneo outcrops like the Melinau Limestone (Adams, 1965).

The main upgrades of Adams to the Letter Classification of 1927 included the addition of previously unrecognized rotalid-dominated zones Ta1 (Paleocene), Ta2 (Early Eocene), while also redefining the original Ta Zone to Ta3 (Middle Eocene). He also compiled a more comprehensive range chart of Indo-West Pacific Cenozoic larger forams, now displayed at species levels. A further update on Cenozoic larger foraminifera came in Adams (1984).

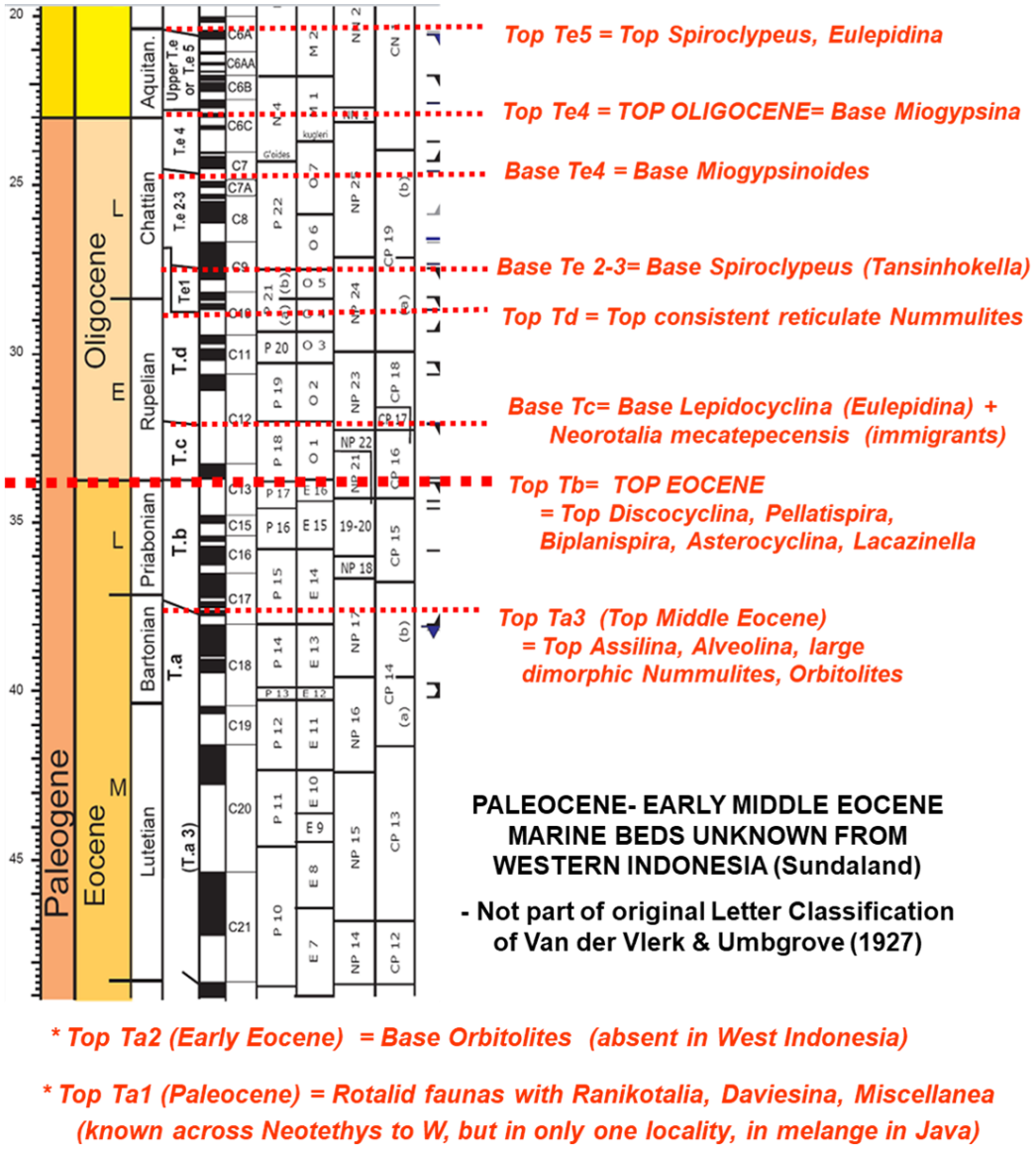


Fig. 24. *Paleogene Larger foraminifera Letter Zonation and 'datum levels. Paleocene and Early Eocene are not detailed here, as they are virtually absent in western Indonesia (Time Scale and calibrations of planktonic foraminifera and calcareous nannofossils biozonations from P. Lunt, in Van Gorsel, Lunt & Morley, 2014).*

The next major improvements to the larger foraminifera zonation in SE Asia trickled in through the late 1960s to the 1980s, when larger foraminifera occurrences across SE Asia started to be calibrated to the newly developed planktonic foraminifera and nannofossil zonations. Key contributions came from Van der Vlerk & Postuma (1967), Clarke & Blow (1969), Haak & Postuma (1975), Chaproniere (1981), Boudagher-Fadel & Banner (1999), Matsumaru (2011) and others, but most of these did not address the Paleogene. At that time, oil company micropaleontological laboratories (especially BP and Shell) and some European universities were at the forefront of this type of research at that

time, no longer in Bandung. This, and the advent of radiometric dating of carbonates by Sr isotopes, allowed more refined calibrations between the Letter stages, planktonic foraminifera and calcareous nannofossils, and the Geologic Time Scale. The current status is shown in Fig. 25.

For the most recent understanding of the Letter Zonation of SE Asia and its calibration to chronostratigraphy, the reader is referred to the recent works by Peter Lunt, today's leading expert on SE Asia foraminifera and stratigraphy (Lunt & Allan (2004), Van Gorsel, Lunt and Morley (2014), Lunt & Luan (2022) and Lunt (2025).

Biostratigraphy versus Strontium Isotope Stratigraphy (SIS)

As stated above, larger foraminifera remain the most important tool for dating Cenozoic carbonates, especially when the evolutionary stages of genera can be factored in to refine the relative position within the 'Letter stages.' Some geologists not comfortable with the biostratigraphy have opted for Strontium isotope ($^{87}Sr/^{86}Sr$) analysis, with mixed results. While Sr-dating of marine carbonates can be a powerful tool, there are restrictions to the method, primarily the requirement for pristine CaCO3 shell material from fully marine environments. Any kind of

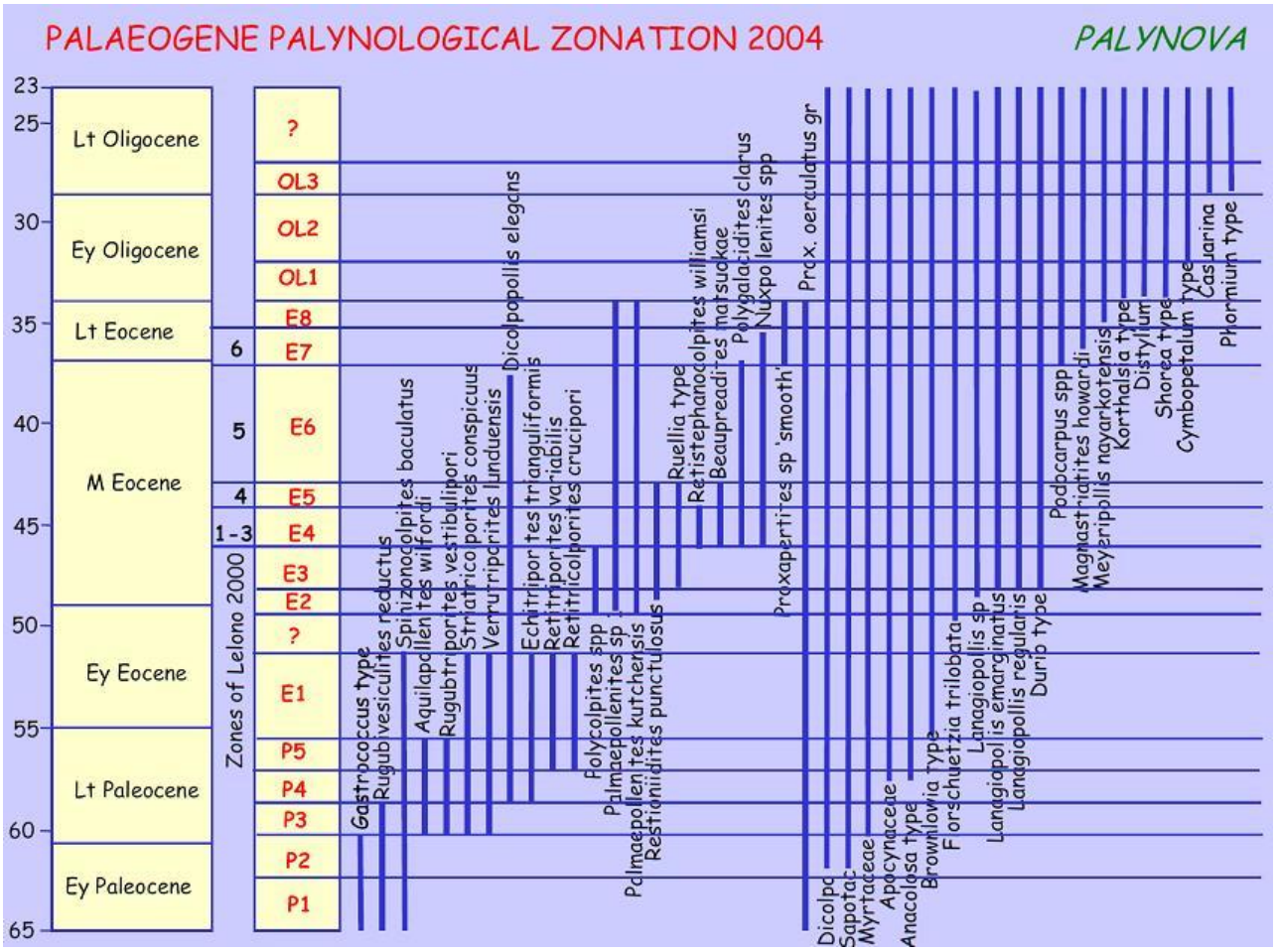


Fig. 25. *Paleogene zonation of palynomorphs (from R.J. Morley, 2004) (see also the similar range chart by R.J. Morley, in Van Gorsel, Lunt & Morley, 2014).*

recrystallization, cementation, etc., causes contamination that produces incorrect results. This problem tends to increase with the age of the fossils. Whole-rock SIS dating, especially carbonates with any kind of diagenesis or cemented limestones, is virtually guaranteed to produce meaningless results

Also, SIS works better in certain time periods and not in others. It utilizes well-documented global trends in seawater Sr-ratios over time. During the Oligocene-Recent period, Sr isotope ratios display a near-linear increase in values, and SIS dating may be quite successful. However, during the Paleocene-Eocene, Sr isotope ratios changed too, slowly and in a non-systematic manner to allow unequivocal interpretations (McArthur & Howarth, 2004).

Finally, it is realized that identifying larger foraminifera may seem like a daunting task to newcomers, because in the past, micropaleontologists spent too much time describing too many new species, with new names for every little variant. However, it is not that complicated. For instance, Van der Vlerk (1928) listed over 57 species of *Lepidocyclina* from Indonesia. For biostratigraphic purposes it generally suffices to be able to recognize a handful of sub-genera, and an estimate of evolutionary stage of the embryon (e.g. Van der Vlerk, 1968, 1973). Another good example of simplification of out-of-control taxonomy of Paleogene nummulitid larger foraminifera in Indonesia was Renema et al. (2002), who found that of the 60 species of Eocene-Oligocene *Nummulites* described from the Indonesian region the past, only seven were believed to be valid species.

FROM THE PALEOGENE TERRESTRIAL WORLD

Palynology: ages and paleoenvironments from the world of vegetation

Prior to the late 1970s, the ages of Paleogene-marine deposits could previously only be 'guestimated' from their position relative to well-dated overlying or underlying carbonate intervals. Since then, much progress has been made in the biostratigraphic zonation of spores and pollen and their calibration to global planktonic marine zonations (Fig. 25).

Paleogene vegetation patterns have been the subject of palynology (pollen-spores) since the 1970s, by R.J. (Bob) Morley, Eko Lelono, A.T. Rahardjo and others, all focused on biostratigraphic, paleoenvironmental and paleoclimatic significance of palynomorphs.

Lots of freshwater swamp palm vegetation in Middle-Late Eocene of SE Asia

Key Eocene palynomorph species in both western Indonesia and mainland SE Asia rift basins like Central Myanmar, include common *Palmaepollenites kutchensis* (a palm from freshwater swamp vegetation) and *Proxapertites operculatus* (R.J. Morley 2004, 2014, Huang et al. 2020, etc.). *P. kutchensis*, which is believed to be a Middle Eocene-age immigrant from India / Gondwana at the start of the Middle Eocene, during or after the India-Asia collision. It became much reduced or disappeared at the transition towards more seasonal Oligocene climates in western Indonesia (Harley & Morley, 1995, Lelono et al., 2007). Lelono (2016) also suggested an earlier decrease in

freshwater palm pollen at the Middle-Late Eocene boundary, suggesting a cooling trend after the early-Middle Eocene thermal maxima, very much in agreement with the decrease in diversity and size of larger foraminifera at that time (Ta-Tb boundary) and the global oxygen isotope curve of Fig. 29.

In western Indonesia, *Palmaepollenites kutchensis* has been reported from Eocene lacustrine deposits in the Sumatra rift basins, including in the Ombilin basin (Bachri et al. 2002), the Pematang Formation 'Brown Shale' in the subsurface Central Sumatra Basin, the Bayah Formation of Ciletuh, SW Java (Winantris et al. 2023), the Tanjung Formation in the Barito Basin, SE Kalimantan (Kristyarin et al. 2016, Winantris et al., 2017), Makassar Straits well(s) (Lelono, 2007), SW Sulawesi (Zulfiah & N. Supardi, 2023) and other areas (Lelono et al. 2014).

EOCENE VERTEBRATE FOSSILS IN INDONESIA

Paleogene mammal fossils are extremely rare in Indonesia and limited to remnants of presumably Eocene-age anthracothere artiodactyls, an extinct Eurasian-affinity group of *Hippopotamus*-like mammals, in NW Kalimantan and Timor. There are also rich Eocene fossil fish assemblages and an important bird fossil from the Ombilin basin in West Sumatra, which will be discussed in Part V.4. Lacustrine deposits).

Relatively rich mammal assemblages are known mainland SE Asia from several Eocene continental deposits, including (1) the coal-bearing Krabi Formation in Peninsular Thailand, (2) the Upper Pondaung Formation of Central Myanmar (~38 Ma; late Middle Eocene) and (3) the coal-bearing Middle-Late Eocene at Na Duong in North Vietnam. These SE Asia mammal fossil assemblages contain common artiodactyl mammals, particularly anthracotheres (*Anthracotherium*, etc.).

Anthracotherid molars from NW Kalimantan

The first Early Tertiary mammal remains from the Indonesian region were reported by Stromer (1931): from probable Eocene beds pf the <elawi Formation at Gunung Sebumban Ulu, Sanggau area, NW Kalimantan. One of two molars is from the pig family, the other belongs to a small artiodactyl mammal named *Artiodactylus* by Stromer, which is a member of a family

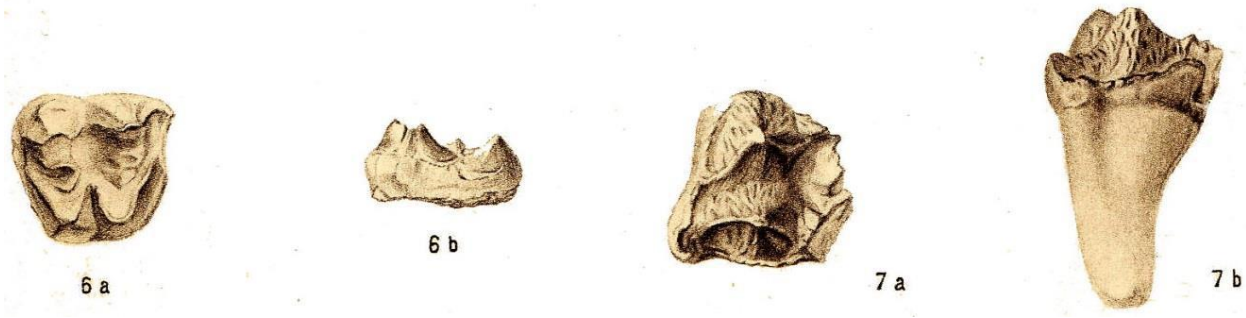


Fig. 26. *Two molars of presumably Eocene age from NW Kalimantan: 6 ab = Choeromorus and 7ab= anthracoceriid (Stromer 1931).*

that is common in the Middle and Upper Eocene of mainland SE Asia (Fig. 26).

Anthracocere from Timor

Von Koenigswald (1967) described a skull fragment with molars of an anthracotherid mammal from a locality west of Laharus, in northern West Timor (Fig. 27). He named it *Anthracothema verhoeveni* n. sp. and assigned it a Late Eocene age based on similarities with faunas known from Eocene of Birma, South China and Thailand. The morphological similarities between the Timor skull fragment and the Middle-Late Eocene mammal faunas of mainland SE Asia were confirmed by Ducrocq (1996) and Tsubumoto et al. (2011).

The fossil was collected by a local schoolteacher, who passed it on to catholic priest and archeologist Father Theo Verhoeven. Von Koenigswald gave few details on the geologic setting of the fossil. However, as narrated in Ducrocq (1996), paleontologist Paul Sondaar of the University of Utrecht revisited the site in 1981, accompanied by the original Timorese collector, and concluded that the fossil had been washed out from sandy deposits near outcrops of Late Eocene *Nummulites* limestone. This confirmed that the fossil was likely associated with Late Eocene rocks and also that it was not brought to this remote part Timor by other, non-geological means.

The importance of this fossil should not be underestimated. Both its Asian affinity and the proximity to *Nummulites* limestones (not known from the undisputed Australian-Gondwanan parts of Timor Island) rather firmly place it as an element of the allochthonous, Eocene

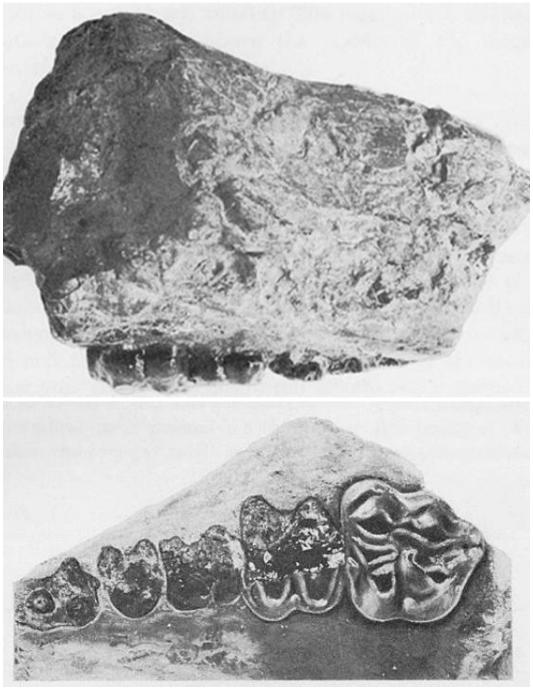


Fig. 27. *Two views of the same skull fragment with molars of Anthracothema verhoeveni (now reclassified as Anthracotherium verhoeveni) from the Eocene of Timor (Von Koenigswald 1967).*

Sundaland margin-derived "Banda Terrane" (also called Palelo, Lolotoi, etc. complexes).

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