THE BAGELEN BEDS, CENTRAL JAWA

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ABSTRACT

The Bagelen Beds of Central Java are re-defined and described as a very deep marine olistostrome deposit of Early Oligocene age (about 32½ MYBP). There is no indication that the clays have been tectonised and they are considered a pebbly-claystone or slump deposit rather than a tectonic *mélange*. The benthic microfaunas are analogous to those found in open-ocean palaeobathymetries at around 3,000 metres, but it is argued that this interpretation may not be applicable to semi-restricted basins in a tectonically complex area. A shallower depth, of very roughly 1,000 to 2,000 m, is argued to be possible and that this would better fit the epi-cratonic geological setting. The significance of a deep marine, slump-filled environment in the Early Oligocene of Central Java is discussed, and a suggestion made for the origin of the unusual mud-volcano found in the Sangiran Dome.

Keywords: Bagelen beds, olistostrome, slump deposit, benthic microfaunas, epi-cratonic

SARI

Bagelen Beds *di daerah Jawa Tengah didefinisikan dan dideskripsikan kembali sebagai batulempung hasil endapan oilistostrom laut sangat dalam yang berumur Oligosen Awal (sekitar 32½ juta tahun). Tidak terdapatnya tanda-tanda tektonisasi pada batulempung tersebut menunjukkan bahwa batuan ini bukan endapan bancuh tektonik* (tectonic mélange), *akan tetapi merupakan batulempung kerakalan* (pebbly-claystone) *hasil proses nendatan* (slump deposit). *Fauna renik bentos menunjukkan kesamaan dengan bentos yang diendapkan pada lingkungan laut terbuka sangat dalam sekitar 3.000 meter. Interpretasi ini mungkin tidak dapat diterapkan pada cekungan agak tertutup pada daerah yang rumit secara tektonik. Dimungkinkan bahwa batuan tersebut diendapkan pada lingkungan yang lebih dangkal sekitar 1.000 hingga 2.000 meter, sesuai dengan keadaan geologi daerah tepian kraton. Arti penting endapan nendatan laut dalam pada zaman Oligosen Awal di Jawa Tengah dan pemikiran tentang munculnya gunung lumpur* (mud volcano) *di daerah Sangiran dikemukakan dalam tulisan ini.*

Kata kunci : Bagelen beds, *olistostrome, proses nendatan, fauna renik bentos, tepian kraton*

INTRODUCTION

The rarely used formation name "Bagelen Beds" is resurrected and emended to cover an unusual facies found at the type location. The original name was defined in 1892 by Verbeek, in the Bagelen southern part of Central Java, during the first geologic reconnaissence of Java. However, four years later the published maps and report on Java by this author and Reinder Fennema (Verbeek and Fennema, 1896) did not use this name, applying a general title "eocene in the Worawari terrane" for the Bagelen locality. The 1896 mapping report describes several more localities of apparently similar age and facies in the northwest Bagelen area, and these were also detailed under the heading of "eocene". The reason for this fall from use was not given, and since then it is only Marks' Stratigraphic Lexicon (1957) which mentions the name at all, and this work considers the name obsolete (see Appendix 1). Therefore in resurrecting the name with an emended description, there is little danger of confusion with any past usage of the term "Bagelen Beds.

A core was taken from the centre of the mapped area of the poorly outcropping Bagelen Beds, and this contained a very deep marine foraminiferal assemblage. This fauna is described here, and the significance of the environmental indicators discussed. The age of the sediments is younger than previously thought and this age determination (Early Oligocene) is qualified, and considered in light of the common Eocene, mostly Middle Eocene, larger foraminifera for which the location was first made famous. Finally the geological interpretation of a deep marine, clay mélange with olistoliths is discussed in light of the regional geology and the evidence from nearby outcrops. Some other locations are suggested to be a similar facies, but other Palaeogene sediments in the NW Bagelen region are distinguished as other ages and facies.

HISTORY OF STUDY

By the end of the 19th century many older Tertiary beds were known from the north-western border of the Bagelen Regency. The first two varieties of *Nummulites bagelensis*, several varieties of *N. javanus, Alveolina javana* and *Discocyclina ephippium* var. *Javana* have their type locations in these outcrops (all defined in the 1891 paper of Verbeek, finally published in 1892), with none having precise locations other than "localities in Bagelen Residency ... " and a selection of names including the Kali Gorang, Kali Suruan, Karangsambung, Pesawahan, Sampang and others, most of which are on the southern fringes of the Lukulo basement outcrop (see Figure 1). Only *N. javanus* var. β is noted as occurring in the Worawari area.

Verbeek and Fennema (1896) (Figure 2) discussed the mapping of the older Tertiary of the Bagelen Residency under two headings, one for the "Lohoelo" or Lukulo terrane, and a shorter account for the geographically separate Worawari terrane. The term Bagelen Beds was not used, however the account for Worawari, and annotation on the map and cross-section of Verbeek and Fennema show a small qualitative difference between this and the other areas. They showed the Worawari area as having a small, southeastern part that was regarded as Oligocene. The reason for this was the occurrence of *Discocyclina dispansa*, which was not recorded from the Lukulo terrains but was known from Nanggulan. At that time Nanggulan was regarded as an Oligocene location on the basis of percentages of extant molluscs, a mistake that would be rectified some 15 years later by Martin (field work in 1910, published 1915). So following the information they had, Verbeek and Fennema interpreted an Oligocene age for a small part of the Worawari terrane. Modern biostratigraphy regards all occurrences of *Discocyclina* as Eocene or older, so this older interpretation is not the same as the Oligocene age assigned by this report.

By the time van Bemmelen (1937) carried out systematic [1:100,000 scale] mapping of the Worawari area, the Eocene age of Nanggulan sediments had been resolved, and larger foraminifera had replaced molluscs as the primary age index fossils for the Tertiary. Van Bemmelen found three more areas of "eocene" sediments to the north of Worawari which he called the Sigugur terrain, the Kalibongbong terrane and the small Kalibodas terrane (Figure 3). With the help of the palaeontologist Tan Sin Hok he listed the species present in each area. The Worawari area, the biggest area of outcrop, had the longest description and faunal list. In all four areas there are fossils representing the T*a* Letter Stage, or Middle Eocene, namely *Alveolina* (specifically identified as the Middle Eocene "*Flosculinella*" types), *Assilina* and species of *Nummulites* we now consider Middle Eocene. A few records of *Pellatispira* do not necessarily have to be indicative of Late Eocene T*b* as suggested by Adams (1970), as there are many records of this genus with T*a* stage fossils (cf. Umbgrove, 1928). Apart from a single reference to radiolaria, no other fossils are mentioned. Within this unit van Bemmelen recorded boulders of polymict conglomerate and sandstone, with clasts of andesite, basalt, granite, crystalline schist and limestone.

Van Bemmelen considered the Eocene to be thrust-over the adjacent Miocene Merawu Beds, which are topographically lower in the northeast, in the valley of the Kali Merawu (cf. van Bemmelen 1949, p.604 and following pages to 616). This tectonic model required thrusting from the north for the three new Eocene terranes, and from the south for Worawari. This contrasts with the older interpretation of Verbeek and Fennema, who reported steep dips of 50°-60° and some vertical beds. In their crosssection of Worawari (Figure 4 here), which is nearly perpendicular to the postulated direction of thrusting of van Bemmelen, they have their Miocene beds [m1] on either side at lower dips, with their "Oligocene" beds also at lower angles, faulted against the near vertical core of the Kali Worawari Eocene.

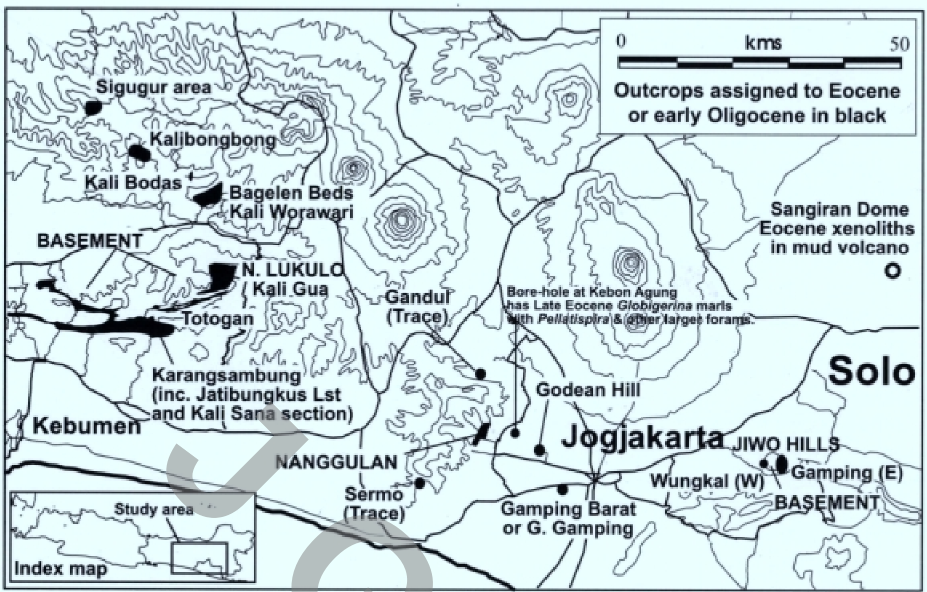

Figure 1. Location map for all the older Tertiary sediments known in the Central Java region

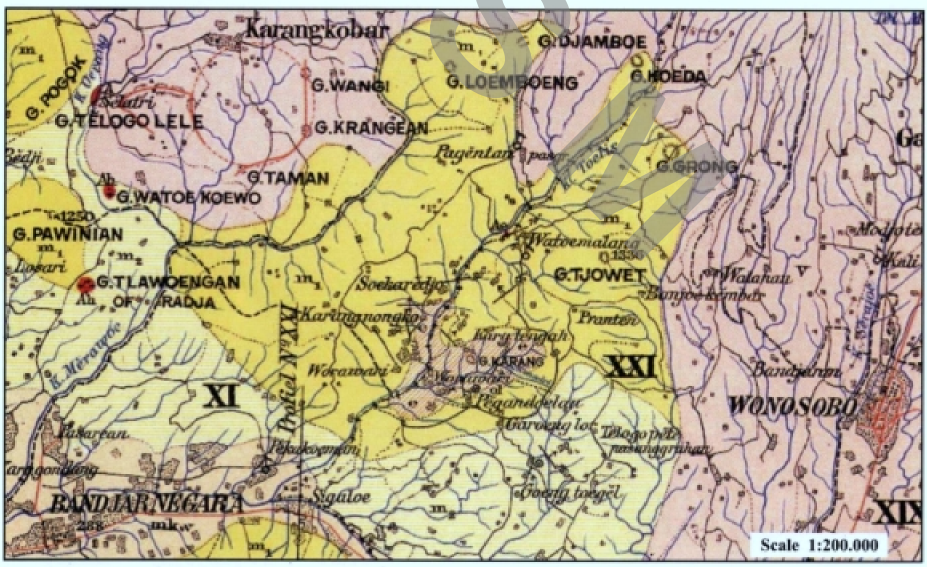

Figure 2. The original map of Worawari, type location of the Bagelen Beds, Verbeek & Fennema 1896 (Banjarnegara to Wonosobo is about 22km in a straight line).

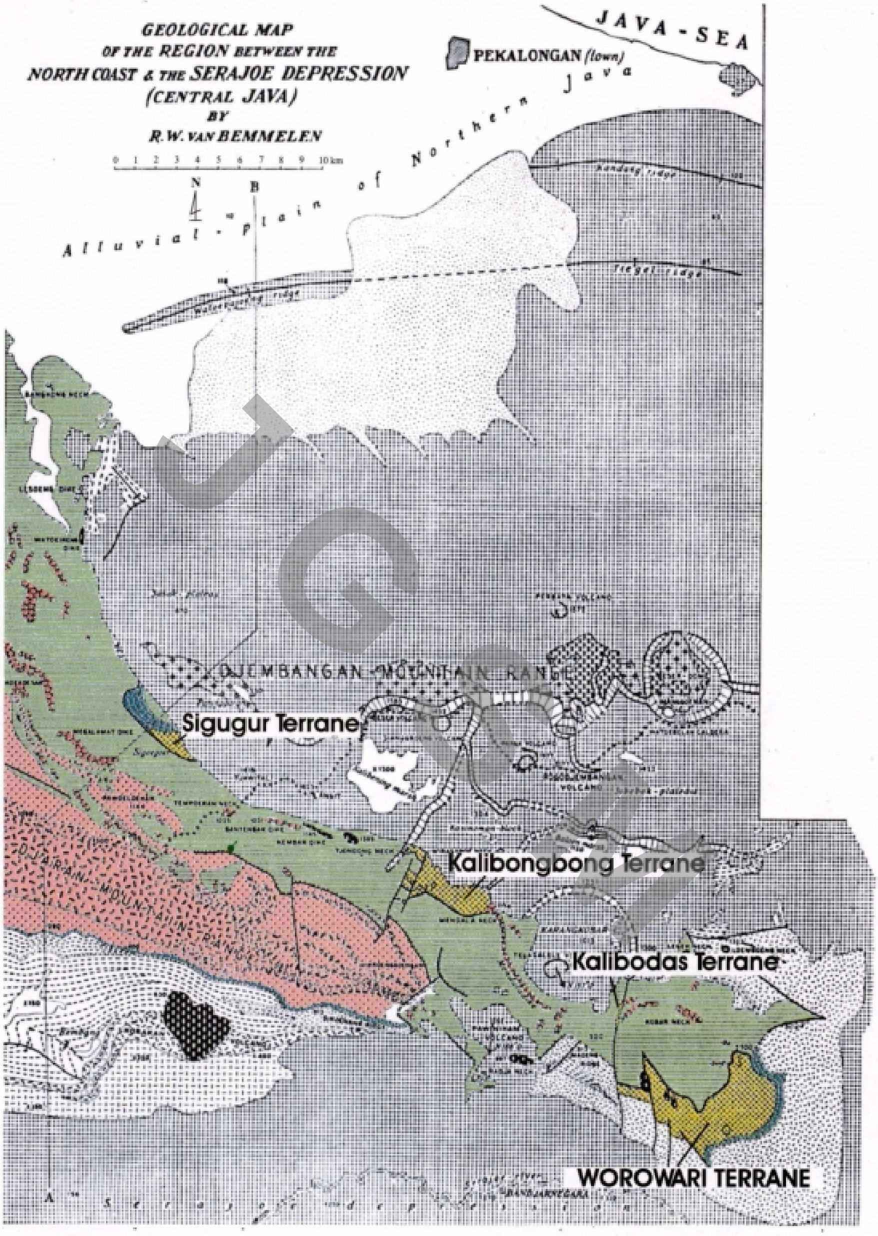

Figure 3. Reproduction of Figure 301 (plate 32) from van Bemmelen (1949), of the general Karangkobar area, showing the four old-Tertiary terranes of van Bemmelen (1937). In this colour version the Palaeogene sediments in the four terranes are yellow, the small blue area in the north is the Sigugur limestone, the thin blue bed in the south is the Bodas Limestone. The green are the Merawu Beds, and the pink the Penyaten Beds.

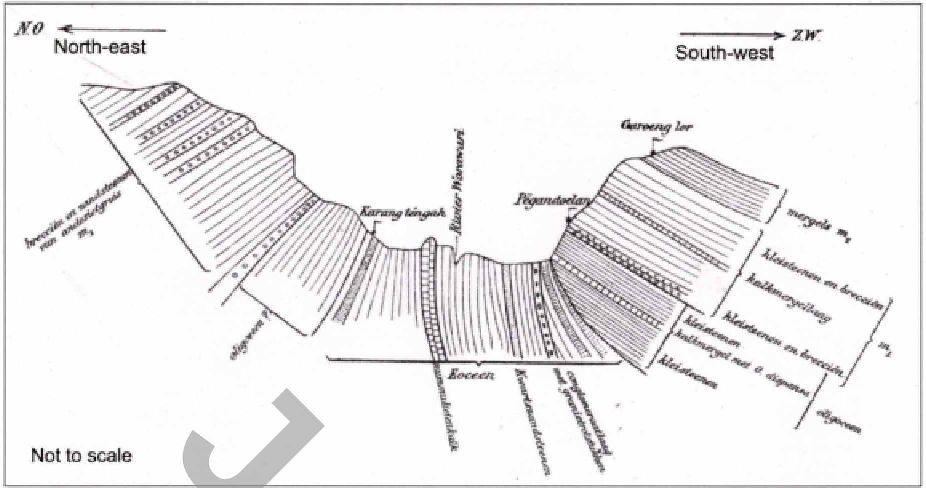

Figure 4. Cross-section of the Eocene terrane in the Worawori River, Bagelen, According to Verbeek & Fennema (1896).

The most recent published account of the region is by the Geological Research and Development Centre [GRDC] (Condon *et al.* 1975). In the notes that accompany their map the Eocene section at Worawari is described as:

"Limestone, locally composed entirely, and elsewhere partly, of *Nummulites* and other foraminifers, coral, and algae, occurs as lenses. These rocks contain fossils that indicate an age range from middle Eocene to Miocene. *Globorotalia opima* BOLLI and *Globigerina sellii* (BORSETTI) from fossil locality Sd Ba 4, and *Globigerina ampliapertura* BOLLI, *Globigerina ciperoensis* BOLLI and *Globigerina sellii* (BORSETTI) from fossil locality Sd Ba 26 suggest an Oligocene age for some of these rocks; *Globigerina boweri* BOLLI, *Globorotalia broedermanni* CUSHMAN and BERMUDEZ. *Globorotalia centralis* CUSHMAN and BERMUDEZ, *Hantkenina mexicana* CUSHMAN, *Truncorotaloides rohri* BRONNIMANN and BERMUDEZ, *Globorotalia bulbrooki* BOLLI, and *Globorotalia bolivariana* (PETTERS) from fossil locality Sd Ba 12 suggest a middle Eocene age for others. These fossils were identified by Sudijono of the Geological Survey of Indonesia" This work by the GRDC is the first record of planktonic foraminifera in the sediments, and also the first non-Eocene age index species from the Bagelen Beds (see Figure 5 for locations).

There are unpublished accounts of an oil industry group attempting to study the area in the 1980's. Photographs by this group of low-angle, thin-bedded, turbidite facies have been traced to a location in the Kali Tulis north of the Worawari area, in facies mapped by all previous workers as Merawu beds, and confirmed as Early Miocene by us (nannofossils noted below, on sample M-10 shown of Figure 5). Original biostratigraphy analyses by this group were inconclusive and the authors only assumed Eocene. There were repercussions from this work as subsequent unpublished industry work cited the "possible Eocene turbidites of Worawari". It was to clarify the age and nature of the Worawari Beds that Coparex (now Lundin) carried out fieldwork and took a core from the centre of the area.

RESULTS OF THE NEW WORK

Work by Lundin geologists included several phases of field work and the drilling of a core to compensate for the very poor exposure in this area.

There are some poor river outcrops along the Kali Tulis, Kali Worowari and some of their tributaries. No bedded strata were observed. The streams contain many boulders of limestone, rich in larger foraminifera of the type described by van Bemmelen, Tan Sin Hok and previous workers. Also present are boulders of quartz sandstone and polymict conglomerate up to several metres in diameter. Basement meta-sedimentary material is found as individual clasts to several centimetres, some in the polymict conglomerate and some loose. There are also large boulders of volcanic material but these may have slumped down from the surrounding hills, especially in the south. The largest outcrops discovered were only a few meters in length and consisted of massive red-grey claystone of an extremely soft nature, showing the effects of erosion by raindrops. The mudstone outcrop samples were devoid of foraminifera or nannofossils, apart from W-2 in Kali Worawari which yielded a good nannoflora indicative of the Late Eocene, probably the uppermost part.

The core drilled near the village of Jebeng in January 1999. The site was chosen as being in the centre of the Worawari area, close to sample W-2 and a concentration of large Eocene limestone boulders and with suitable firm track access. Using hand held GPS (prior to cancellation of selective availability, so accurate only to about 50 metres) the location of the core was:

7°21'24.42"S, 109°47'39.37"E - 9,186,708S, 366,935E, (UTM projection, Bessel 1841, CM 111° [zone 49 South])

Total Depth: **99.5 m**, core recovery about 85%

The core drilled a monotonous, unbeddedclaystone. The clay was soft, and prone to swell in the core boxes. It is variably coloured, in part pale greenish grey but with large sections strongly coloured ferrous green and other parts ferric red. The green coloured clay was often associated with small amounts of pyrite, and these chemically reduced zones were sometimes elongate as if following a burrow. The red-stained clay had no pyrite and yielded the best calcareous fossil assemblages. All colour changes were irregular and did not show any bedding. Quite distinct when the core was fresh or wet was a "scaly" fabric, in that the clay tends to dry and disintegrate into centimetre-scale irregular laths or flakes, with no preferred alignment. Early on this led to the use of the term "scaly clay" although it must be stressed that this scaly nature appears to be the result of synsedimentary disturbance of the clay matrix and not a later tectonic fabric. No slickensidelike fissility is observed and there are no white micas from low grade metamorphism. In the entire core not one single lamination due to grain-size variation, or diastem could be recognised.

The core was washed for microfossils at 2 metre intervals with later fill-in samples. An experiment was carried out on one kilo of core sample. This sample was washed through a 63μm sieve mixed only with detergent, and no physical disaggregation stronger than a mild jet of water. All that was left was a small residue of 14 grams (=1.4%), most of which was pyrite, pyrite-cemented clay and other diagenetically lithified claystone fragments. This demonstrated the high proportion of an extremely soft, water-dispersive clay in the sample.

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MICROFOSSILS PRESENT

The samples yielded very sporadic planktonic foraminifera, which are discussed in the section on biostratigraphy. Locally abundant in the green, pyritic clays were radiolaria, preserved as pyrite casts. Almost all samples yielded some benthic foraminifera, usually in very small amounts. Consistently present were undifferentiated *Haplophragmoides / Trochammina* forms. In most samples it was possible to identify *Trochamminoides proteus* (Karrer), *Haplophragmoides scitulum* (Brady) and *Haplophragmoides compressa* LeRoy. Also consistently present was *Glomospira*, mostly *G. charoides* (Jones & Parker), as well as Bathysiphon, and less often *Saccammina / Reophax* types. Also present in most of the samples were specimens very similar in form to *Cyclammina pusilla* Brady.

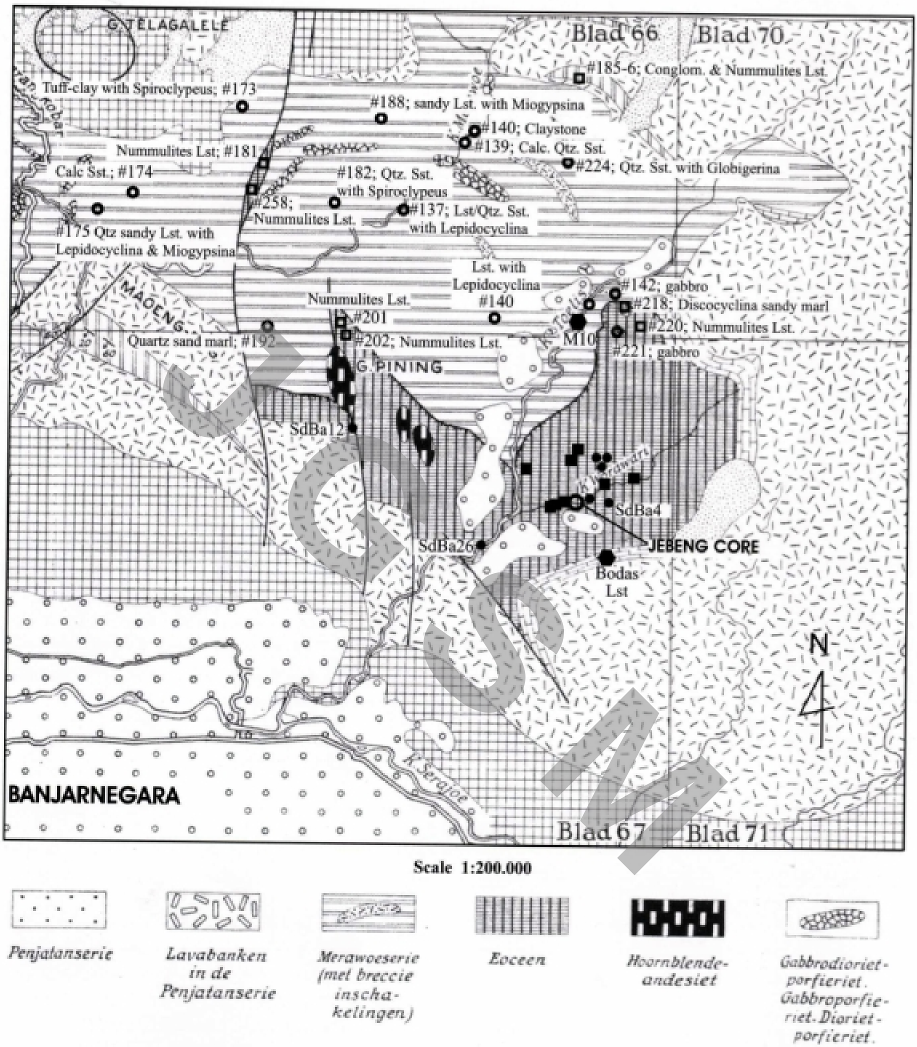


Figure 5. van Bemmelen's 1937 map for Worawori (Eocene), with annotations from his original and subsequent GRDC / Lundin samples. van Bemmelen's Merawu Beds samples with Neogene fossils and quartz sand, open square symbols his samples of Eocene limestone / sandy limestone. Solid square samples are Eocene limestone samples collected for this study, solid circles are other samples of older Tertiary mudstones, including the three fossiliferous samples of the GRDC study. Hexagonal symbols are the Late Miocene Bodas Limestone, and M-10 with nannofossil data on the Merawu Beds.

Rarer arenaceous taxa present as one or two specimens in about half the samples were *Spiroplectella earlandi* (Reuss), *Spiroplectammina arenacea* LeRoy, *Vulvulina pennatula* (Batsch) and *Ammodiscus incertus* (d'Orbigny). Also present in small numbers in many samples was a thick walled calcareous stilostomellid foram, probably belonging to Nodogenerina lepidula (Schwager). In addition to these forms there are many species which occur as only a few individuals in the many samples examined, these include approximately in order of abundance:

- aff. *Buliminella* – globose species
- *Oridorsalis umbonatus* (Reuss)
- *Gyroidinoides soldanii* (d'Orbigny)
- *Gyroidina? regularis*
- *Globocassidulina subglobosa* (Brady)
- *Cibicidoides* aff. *grimsdalei* (Nuttall)
- undiff. *Cibicidoides* forms
- *Textularia* spp.
- *Gaudryina* cf. *cylindrica* Nuttall
- *Pleurostomella alternans* (Schwager)
- *Oolina* / *Lagena* sp.
- *Fissurina* spp.
- *Lenticulina* spp.

Single specimens of the following were observed:

- *Laterostomella* sp.
- *Sphaeroidina bulloides* (d'Orbigny)
- *Pullenia quinqueloba* (Reuss)
- *Marginulina* sp.

PAUCITY OF PLANKTONIC FORAMINIFERA AND ENVIRONMENT

Planktonic foraminifera are present in only a few samples, with just 3 poor faunas out of nearly 60 samples. The tests show signs of dissolution with loss of both spine bases and detail around apertures. In contrast to the sparse planktonic foraminifera there are locally abundant pyritised radiolaria in the reduced, green clay, which demonstrates the existence of open ocean plankton production at the time of deposition (the very delicate spines mentioned above rule out reworking as an origin for the radiolarian fossils). The abundance of radiolaria also show that high rates of sedimentation are not diluting, or tubidite conditions abrading and destroying, the planktonic microfossils. The relative paucity of planktonic foraminifera, and the state of preservation of the few that remain, suggests dissolution of calcareous microfossils. This is usually thought to indicate a deep marine setting.

BENTHIC SPECIES AND ENVIRONMENT

By analogy with open oceanic benthic foraminifera, the composition of the microfauna suggests a very deep environment of deposition. The work of Saidova (1959, 1960a,b, and 1961), based on abundant material from the NW Pacific, Japan, Bering and Okhotsk Seas, concluded that calcareous benthic foraminifera are most abundant between 400-1500m and are very rarely found below 3500m. Only arenaceous foraminifera live in the benthos below 3500m. She also noted that from 3000m and below, the arenaceous foraminifera often have complex tests. Below 3500 metres, however, such complex types diminish, until the deepest faunas are of "primitive" type such as Haplophragmoides, *Bathysiphon, Reophax, Saccammina* and similar forms. Bandy and Rodolfo (1964) studied the benthic foraminifera assemblages in the Peru-Chile trench and found very similar results. Lukina (1967a,b) found similar results in the central Pacific. Both these last groups of workers noted survival of small numbers of certain calcareous foraminifera to considerable depth. Bandy and Rodolfo noted consistent *Stilostomella antillea*, a form extremely similar and possibly related to the aff. *Nodogenerina lepidula* recorded here, to be particularly resistant to dissolution and found as deep as 6001 m. Other resistant calcareous forms include Lagenids, *Fissurina, Gyroidina orbicularis, Planulina rugosa*, some Uvigerinids, Globocassidulina *subglobosa* and *Siphovigerina* types, found in small amounts as deep as about 6500m.

The overall composition of the benthic fauna in the Jebeng core samples is very similar to the faunas described by the above authors from roughly 3000 metres to 6000 metres. The presence of arenacous types with complex walls, such as aff. *Cyclammina pusilla* compares best with the upper part of this range, at about 3000-3500 m. The present day water-depth ranges of extant species are given with the taxonomic notes below. Some of these are very wide ranging such as *Globocassidulina subglobosa* (as shallow as 50m, Jones 1994) but most have upper depth limits around a few hundred metres, and all of them have been recorded from depths of several thousand metres.

The two most widely used references on Indonesian deep water foraminifera are by van Marle (1988) who characterised faunas down to 2120m in the troughs around Seram, Tanimbar and eastern Timor, and by Loeblich and Tappan (1994) who made a taxonomically detailed compendium of the Timor Trough just west of van Marle's area. Loeblich and Tappan examined samples from as deep as 3200m but do not detail assemblage composition against depth. Van Marle mostly described assemblages rich in calcareous foraminifera which therefore do not compare to the material here. In his deepest zone D (1400-2120m) the taxon *Oridorsalis umbonatus* (Reuss) and *Pullenia* species are considered significant markers, occurring with increasing numbers of *Alveophragmium* spp., *Glomospira* and *Martinotiella* spp. His deepest samples, below 1600m, have diminishing numbers of planktonic foraminifera due to dissolution, and at the same depth increasing arenaceous forms as a percentage of the benthic fauna (but only to about 20%). In these deepest samples van Marle notes increasing abundance of the arenaceous forms "such as *Alveophragmium* spp., *Eggerella bradyi* (Cushman), *Glomospira charoides* (Jones & Parker), *Glomospira gordialis* (Jones & Parker), *Karreriella bradyi* (Cushman), *Martinotiella* spp., *Textularia* spp., *Sigmoilopsis schlumbergeri* (Silvestri) and *Vulvulina pennatula* (Batsch)". It is these deepest samples that best compare to the faunas of the Jebeng core.

The Gulf of Mexico palaeobathymetric interpretations of many authors was refined to a generic level classification by Culver in 1988, which allowed its use outside the west Atlantic basins. This scheme has been used in oil-industry work in Indonesia. The assemblages at Jebeng correlate best with Culver's Zones 12 or 13, which equate to depths of 1501 to 3000m, or deeper than 3000m respectively. Above Zone 12 the high proportions of the cosmopolitan calcareous species *Bolivina, Bulimina, Cibicides* and *Gyroidina* appear to rule out a correlation with the Jebeng assemblage.

CONCLUSION ON ENVIRONMENT OF DEPOSITION

The overall composition of the benthic and limited planktonic microfauna points to a depth of deposition at which calcium carbonate is becoming undersaturated in the benthos. The only factors known to cause such undersaturation are the high pressure, low temperature conditions that create the open ocean lysocline / CCD, and increased acidity in dysaerobic conditions with high organic carbon preservation. The presence of fluctuating reduced and oxidised lithologies in the Jebeng core indicate that the sediments were not well oxygenated, although the foraminiferal faunas are recovered only from the redder, oxidised beds (which contain no pyrite). It should also be noted that the lithology contains very little visisble organic carbonaceous material, such as the fine lignite flakes commonly seen in deep water exploration well samples in front of major deltas around Indonesia.

So while direct analogy with open marine analogs suggests a palaeobathymetry of 3,000 metres for the Bagelen Beds in the Jebeng core, there is evidence, and less studied analogs, that indicate a significantly shallower environment of deposition is possible. Umbgrove's (1949) review of modern basin conditions around Indonesia notes that "the depth at which a sediment is deposited is not a factor of primary importance to its percentage of calcium carbonate." (p.18 *op.cit*). Umbgrove suggested two other influences that control calcium carbonate concentration, one is dilution by sediment, such as near active volcanoes or large deltas, a factor discounted - or of reduced importance - here as illustrated by the abundance of pelagic radiolaria noted above. His second factor is the local expression of the lysocline or CCD in the sub-basins around the archipelago, in which the temperature and oxygen concentration of deep waters is not the same as in the open ocean. These sub-basins are silled at depth by geologic barriers, so that within them the deep benthic conditions cannot be compared to the open ocean, or even to each other (see figure 18 *op.cit*.). The Timor Trough area studied by van Marle and Loeblich & Tappan, cited above, differs from these silled basins as it has the best deep connections to both the Indian and Pacific Oceans. It is not surprising then that this areas has highly calcareous sediments and common calcareous microfauna at least as deep as 2,000 metres. It is important to note that the tops of the geologic barriers separating these silled basins are between 1,000 and 3,000 metres deep. As such they will not seed reefs nor yield erosive products to leave behind an obvious geologic record. Therefore, as we do not know the configuration of the basin into which the Bagelen Beds were deposited, we can either assume completely open connection with the open ocean and a water depth of around 3,000 meters, or we could postulate barriers (which seem very likely based on the regional geological knowledge of Java) and admit error in palaeobathymetric interpretation to somewhere as shallow as about 1,000 metres. There are good reasons to believe water depths could not have been shallower than about a thousand metres. Most importantly, the gradual base of the permanent thermocline is at about this limit in the tropics (Schopf, 1980, van Marle, 1988, Hofker, 1978), above which $CaCO_3$, temperature and oxygen concentrations are increasingly affected by surface activity.

PLANKTONIC SPECIES AND THE AGE OF THE SEDIMENTS

Radiolaria

Prior to the location of samples containing calcareous plankton, when the published Eocene age of the sediments was still assumed to be correct, an examination was made of the pyritised casts of radiolaria. The aim was to compare the pyritised forms with four known Middle Eocene radiolarian assemblages from Nanggulan and Karangsambung.

While the four known Middle Eocene assemblages contained many distinct radiolarian morphotypes such as *Spongotractus balbis / S. pachystylus*, the *Lithocyclia aristotelis* group with distinctive armatures, and the tetrahedral *Stethochytris triconiscus*, none of these forms were found in the Jebeng core. These taxa are usually frequent in low latitude Middle Eocene sediments (Ngirini and Sanfilippo, 2001) and have profiles that would be distinctive even after pyritization. Of the robust cyclindro-conical forms seen in Jebeng samples none have the distinct abdomen of the Late Eocene marker *Calocyclas turris* Ehrenberg, but a few specimens might be referable to *Theocyrtis tuberosa* Riedel, emend. Sanfilippo *et al*. This species is common in late Late Eocene to early Late Oligocene assemblages from low and middle latitudes of all ocean basins (Ngirini and Sanfilippo, 2001).

This examination of the poorly preserved radiolarian assemblage at Jebeng could only conclude that they are substantially different to four Middle Eocene assemblages from the same region. The tentative identifications in the Jebeng samples are more consistent with, but not confidently diagnostic of, a younger age.

Foraminifera

A few levels in the upper part of the core were found to yield calcareous planktonic fossils in more than trace amounts. Samples below about 24 metres have planktonic foraminifera present in only a few samples, and then as one or two small "*Globigerina*" specimens. Only 3 of the uppermost samples had sufficient numbers to attempt a biostratigraphic analysis.

Simple globigerine forms dominate, and some of these have distorted final chambers making identification difficult. In addition to *Globigerina* sp.indet. there are long ranging taxa such as *Globigerina venzuelana* and *Catapsydrax dissimilis* indicating a mid Eocene to early Miocene age. No specimens can be referred to the Eocene *Turborotalia* lineage which is usually a major component of pre-Oligocene faunas. Also absent is the distinct, and diagenetically resistant Eocene form *Hantkenina*, which can be identified from fragments. On the other hand, the absence of the species, *Chiloguembelina cubensis* and *Pseudohastigerina micra* is not surprising as these very small, dissolution-prone species are usually lost in poorly preserved assemblages. Only a very few individual markers with narrow age ranges are recorded, and these are taxonomically difficult morphologies.

A few specimens of *Paragloborotalia opima nana* are recorded, about 250μm in diameter and well below the 380μm threshold that defines *P. opima opima* according to Bolli and Saunders (1985). This species first appears in the Eocene and continues into basal Late Oligocene P22. A few small specimens are referred to *Globigerina ampliapertura*, reasonably well formed but a little smaller than typical size. This species evolved in latest Late Eocene and became extinct at the top of zone P19. Assuming the absence of *Turborotalia* types is significant, then this sample can be dated as P18 or P19, Early Oligocene. This age should be regarded as tentative considering the lack of morphologically distinct markers in a sparse assemblage.

Nannofossils

Valentino Quidayan at PT Geoservices (1999, unpublished) examined three Jebeng core samples for nannofossils. Of these, a composite sample from between 6 and 8 metres in the core, close to the best calcareous foraminifera recovery, yielded the only useful nannoflora. This sample contained the following forms

- *Chiasmolithus altus* rare
- *Chiasmolithus titus* rare
- *Coccolithus pelagicus* rare
- *Coronocyclus netescens* rare
- *Cyclicargolithus floridanus* abundant
- *Dictyococcites bisecta* rare
- *Discoaster deflandrei* rare
- *Discoaster tani nodifer* rare
- Erisonia formosus rare
- *Helicosphaera euphratis* rare
- *Reticolufenestra hampdensenis* rare
- *Reticulofenestra hillae* common
- *Reticulofenestra umbilica* frequent
- *Sphenolithus distentus* common
- *Sphenolithus moriformis* rare
- *Sphenolithus predistentus* common
- *Sphenolithus pseudoradians* rare
- *Zyghrablithus bijugatus* rare

The stratigraphic range of the important taxa can be calibrated to the zonations and geomagnetic polarity time scale (GPTS) in Berggren *et al*. (1995). This work places the extinction of *Sphenolithus praedistentus* at 27.5 MYBP, the whole range of *S. distentus* from evolution as old as 32.3 MYBP (but noted by Berggren et al. to be inconsistent and may appear as young at 31.5 MYBP) to extinction at 27.5 MYBP. The frequently occurring *R. umbilica* and the common *R. hillae* both have extinctions placed at 32.3 MYBP, so these last two forms should therefore only overlap with *S. distentus* very close to 32.3 MYBP.

Rarer markers consistent with this age include *Reticulofenestra hampdenensis* and *S. pseudoradians* which have extinction datums in the middle part of the total range of *S. Distentus,* and *Chiasmolithus altus*, which has a range from within early Oligocene to within late Oligocene, about 33 to 27 MYBP.

The same analyst also examined a sample from the Merawu Beds in Kali Tulis just north of the Worawari outcop area (M-10 on Figure 5). The occurrences of *Helicosphaera ampliaperta* and *Sphenolithus heteromorphus* indicates an age in the upper part of the Early Miocene, zone NN4 or upper NN3. This is next to where re-examination of van Bemmelen's field samples has observed Early Miocene larger foraminifera in sandy turbidite sediments (report in prep.)

Sr dating and conclusion of age.

To resolve the weakness in biostratigraphic age dating a number of specimens of the thickly walled calcareous foraminifera aff. *Nodogenerina lepidula* were submitted for age determination by correlating $^{87}Sr/^{86}Sr$ stable isotope ratios to known sea-water calibration curve (cf. McArthur, 1998, for recent review of this technique). The result of this analysis detailed below gave an age of 32.6 MYBP, with a precision and correlation error range from 32.1 to 33.0 MYBP. This data is calibrated to the same GPTS as the biostratigraphy data in Berggren et al. (1995) which dates foraminiferal zone P18 to P19 as between 30.3 and 33.8 MYBP, and nannofossil datums described above suggesting an age very close to 32.3 MYBP.

For comparison, the top Eocene as defined by biostratigraphers is usually taken at 33.8 MYBP, the extinction of a number of Eocene (P17) taxa, and close to the evolution of *C. chipolensis*, or the extinction datum of *Discoaster barbadiensis* and *D. saipanensis* at about 34.2 MYBP. The Early to Late Oligocene boundary is placed at the extinction of *Chiloguembelina cubensis* at 28.5 MYBP. The samples analysed therefore are dated as being in the early part of the Early Oligocene, for the sake of simplicity referred to as c. 32½ MYBP.

Jebeng Core samples 8 m. Sr Isotopic Composition and Calculated Ages

SAMPLE	$^{87}Sr/^{86}Sr$	2 sem (%)	Age (Ma)	Precision & error
JEB 8	JEB 8	0,70040	32.5	32.1 to 33.0 MYBP (near base Oligocene)

$^{87}Sr/^{86}Sr$ 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 87Sr/86Sr = 0.710247 ±0.0021% (±0.000015) (95% confidence limits) 2 sem - 2 standard errors of the mean ($2\sigma/\sqrt{n}$). Modern seawater (Mobil) $^{87}Sr/^{86}Sr$ = 0.709168 Ages calculated from McArthur *et al*. (2001). Precision and error figures are a guide to an acceptable range of ages based on machine precision to standard deviation correlated to high and low values within the robust range of data in the McArthur *et al*: correlation curve.

CSIRO (T. Allam, pers. comm.) note that they have measured ratios close to this value from limestones with Tb larger foraminifera in PNG, so Sr data cannot rule out a latest Eocene age.

TAXONOMIC NOTES

The following taxonomic notes are only for key species in the assemblage. There are many hard to identify forms present as only one or two specimens, especially distorted, soft-walled arenaceous foraminifera, which are not discussed.

Class FORAMINIFEREA J.J. Lee 1990
Order ASTRORHIZIDA Lankester 1885
Superfamily ASTRORHIZACEA Brady 1881
Family BATHYSIPHONIDAE Avnimelech 1952
Genus ***BATHYSIPHON*** M.Sars, in G.O.Sars 1872

Notes: The genus *Bathysiphon* has numerous Tertiary species, but poorly defined species concepts in a morphologically simple elongate tube test, which may often be broken fragments of *Rhabdammina* tests. Many workers do not report this form, as with poor preservation there is always the risk it can be mistaken for an elongate cementation feature. It has been shown to occur shallower in cold waters at high latitudes (cf. Jones 1994, Pl.26, fig 15,17-20 from Hardanger Fjord, Norway, max. depth 640 metres). In low latitudes such elongate arenaceous tests are generally found more frequently in bathyal or abyssal deposits below about 500m (cf. Jones 1994). Van Marle (1988) records it only in his second deepest sample from the trenches of east Indonesia (1816 m)

Family AMMODISCIDAE Reuss 1962
Genus ***AMMODISCUS*** Reuss 1862
Ammodiscus incertus (d'Orbigny, 1839)

Notes: Jones (1994, p. 43) discusses the synonomy of this species, which at least overlapps with the species concepts of *A. tenuis* (Brady) and *A. Intermedius* (Höeglund), if not wholly synonymous with them. Jones (1994) compiles a depth range of 400-1350 fm (Fathoms, =1.83m) or 732 to 2525 metres in the Challenger expedition material.

Genus ***GLOMOSPIRA*** Rzehak 1885
Glomospira charoides (Jones & Parker, 1860)

Notes: This species has been placed in a new genus *Repmanina* Suleymanov 1966 by Loeblich and Tappan 1987, and *Usbekistania* by Charnock & Jones (1990). However neither name has yet been widely adopted. The frequent, locally common forms in the Jebeng core are dominated by types which coil around a single axis so this name is preferred to the alternative, *G. gordialis* (Jones & Parker). Jones 1994 reports a depth range from estuaries to abyssal plain (4500 m). Van Marle (1988) highlights it as a bathymetrically significant taxon with a highest significant range around 600 m and occurring until his deepest sample (2,120 m) with gradually increasing frequency with depth. Loeblich and Tappan (1994) note it at 292 m, 1,238 m and 2,248 m in the Timor Trough. Culver (1988) ranges the genus as high as between 100-150 m but becoming a consistent and significant marker below 1000 m and into abyssal depths.

Family HAPLOPHRAGMOIDIDAE Maync 1952
Genus ***HAPLOPHRAGMOIDES*** Cushman 1910

Notes: The genus *Haplophragmoides* is found concentrated in two widely separate niches, a fact recognised by Saidova (1959) and summarised in Culver's 1988 review at generic level where he has members of this genus in estuarine settings, where organically cemented arenceous forams can thrive in the absence of competitors that require calcium carbonate for their tests, also the genus is found in increasing numbers below 1000 m

Haplophragmoides scitulum (Brady, 1881)

Notes: In the past 15 years it has been placed in numerous other genera in the Haplophragmoididae, suggesting a confused species concept. Jones (1994) who calls it *Veleronoides scitulus* (Brady) notes it has been found between 400 and 2,900 fm or 732 to 5,300 metres. This form is distinguished by the well formed umbilical depressions. No information on the type of aperture is available from these samples and specimens.

Haplophragmoides compressa LeRoy, 1939

Notes: This species was defined in the Miocene of Central Sumatra and is distinguished by its delicate, compressed and distorted shape. LeRoy suggests a relationship to *H. excavatus* Cushman & Waters. No precise data is available about its environmental preferences.

Family LITUOTUBIDAE Loeblich & Tappan 1984
Genus ***TROCHAMMINOIDES*** Cushman 1910
Trochamminoides proteus Karrer, 1866

Notes: An irregularly coiled species, larger than *Glomospira* and with distinct chambers. *Trochamminoides proteus* Karrer is a species recognised by van Marle (1988) but no environmental information is given. Loeblich and

Tappan (1994) note a range between 700 and 2,960 metres. Brady (1884) identified a number of illustrations as from this species (Pl. 40, figs. 1-3), although Jones (1994) did not follow this taxonomy. Brady's figures were of specimens from 390 and 675 fm (714 & 1235 m) but no more detailed bathymetric data is given.

Family CYCLAMMINIDAE, Marie 1941
Genus ***CYCLAMMINA***, Brady 1879
aff. *Cyclammina pusilla* Brady 1881

Test free, maximum size close to 1 mm. Planispiral, biconvex, almost wholly involute. Wall of fine arenaceous composition with smooth outer surface. Three whorls in adult, approximately 15 chambers in final whorl, sutures weakly defined as slightly limbate, radial groves. Spiral margin acute, slightly lobulate in axial view. Outer margin often developed as narrow flattened flange. There is a slight umbilical depression, on both sides. The test walls are relatively thin, however the wall can be seen to contain distinct alveloaé up to 40 or 50 μm in diameter, appearing slightly smaller from the outside of unbroken tests. In external view the alveolae appear as pale blemishes below the smooth, outer test wall and can be seen to have slight radial alignment. Aperture not visible in the specimens available. No obvious openings seen along the base of the apertural face, but some specimens have a rougher texture on the apertural face.

Notes: This form compares very favourably with *Cyclammina pusilla* Brady, with their characteristic small size (both have maximums of c. 1 mm), the number of chambers in the final whorl, the thin sharp, lobulate periphery, the thin wall, and "The cancellated structure is but little developed, there being only sufficient to form a superficial reticulation over the inner surface of the chamber walls." (Brady, 1881).

The are some doubts as to whether such a thinwalled form belongs in Cyclammina as defined in Loeblich & Tappan 1988. The alternative would be the simpler taxon *Alveophragmium*, which is often mentioned in the environmental summaries quoted here.

Jones (1994) reviewing Brady (1884) notes the depth range for *C. pusilla* is 1,675-1,900 fm or 3,065 to 3,477 metres, however it is not a geographically widespread species, being found mostly in the South Altlantic and Southern Ocean. In the Jebeng core samples it is a consistent and locally frequent species

Superfamily SPIROPLECTAMMINACEA Cushman 1927
Family SPIROPLECTAMMINIDAE Cushman 1927
Genus ***SPIROPLECTELLA*** Earland 1934

Notes: The type species for this genus is *S. cylindroides* Earland 1934, a form with a longer uniserial stage than *S. earlandi* and rounded, not angular margin. However it is interesting to note that the type specimens was taken from waters of 3,624 m, off Nova Scotia.

Spiroplectella earlandi (Reuss),

Notes: This species was found by the Challenger expedition near the Kai islands in 140-155 fm. (256 to 284 m; in Jones 1994). This location is within the study area of van Marle (1988) who mentions the taxa in his species list, but does not record it in any of his data charts suggesting it to be a rare form, as omissions of more frequent forms from his data tables are explained individually. In the same general area Loeblich and Tappan (1994) find this species but only cite one location, at a depth of 165 m.

Order BULIMINIDA Fursenko, 1958
Superfamily STILOSTOMELLACEA Finlay 1947
Family STILOSTOMELLIDAE Finlay 1947
Genus ***NODOGENERINA*** Cushman 1927
aff. *Nodogenerina lepidula* (Schwager, 1866).

Notes: The specimens recorded here compare well with those illustrated by Loeblich and Tappan (1994) from the Timor-Roti area (from 165 m and 2,528 m). The range of forms also compares with the type illustration of *Nodogenerina antillea* and *N. virgula*. Within the forms lumped as aff. *N. Lepidula* here are fragments of individuals possibly belonging to *Stilostomella* and *Orthomorphina* with a much slower rate of chamber enlargement and larger protoconch. Information on the palaeobathymetry of such forms is sparse except for the comment above from Bandy and Rodolfo (1964) that these forms can survive in benthic assemblages to depths of around 6,000 m.

Superfamily CASSIDULINACEA d'Orbigny 1839
Family CASSIDULINAIDAE d'Orbigny 1839
Genus ***GLOBOCASSIDULINA*** Voloshinova 1960

Globocassidulina subglobosa (Brady 1881)

Notes: This species, in a virtually monospecific genus, is found at water depths from 12 to 2950 fm (22 to 5,400 m) in Challenger expedition material (Jones, 1994). Culver (1988) does not distinguish this from the broader genus concept of *Cassidulina*. Van Marle observes the wide range of this species in his samples but has an acme of specimens in his deepest sample at 2119m.

Order ROTALIIDA Lankester 1885
Superfamily DISCOBINELLACEA Sigal 1952
Family PARRELLOIDIDAE Hofker 1956
Genus ***CIBICIDOIDES*** Thalmann 1939

Cibicidoides aff *grimsdalei* (Nuttall)

Notes: The forms seen in several samples in the Jebeng core are extremely close to the definition in van Morkhoven *et al*. (1986). They are 0.45 to 0.5 mm in size with the flat spiral side and nearly hemispherical ventral side, and the pitted and wrinkled appearance of the dorsal side, with limbate sutures and coarsely perforate areas. We only hesitate in placing the form in *C. grimsdalei* as the illustrations of van Morkhoven et al. showing some pitting on the ventral side, which is not seen here.

According to van Morkhoven *et al*, (*op. cit*. p. 249) "*Cibicidoides grimsdalei* was primarily a lower bathyal and abyssal taxon. It occurs in greatest abundance in material of early and middle Eocene age from depths of about 2,000 to 4,000 m at sites studied by Tjalsma and Lohman (1983). Miller (personal commun.) reported last occurrences of *C. grimsdalei* to range from early Oligocene Zone P18 at bathyal sites to latest Oligocene or earliest Miocene Zone N4 at sites deeper than 3,000 m."

Superfamily CHILOSTOMELLACEA Brady 1881
Family ORIDORSALIDAE Loeblich & Tappan 1984
Genus ***ORIDORSALIS*** Andersen 1961

Oridorsalis umbonatus (Reuss).

Notes: *Oridorsalis* has a distinctive profile and supplementary aperture. *O. umbonatus* (Reuss) is noted by Jones (1994) as having a range of 166 to 3,125 fm (303 to 5,720 m), Van Marle (1988) notes a similar upper depth limit, but suggests it as a marker for his deepest zone D assemblage, for depths of 1400 to his deepest samples at 2,120 m. It is worth noting that according to Loeblich & Tappan (1988, p. 631) the genus *Oridorsalis* is not recorded before the Oligocene.

Family GAVELINELLIDAE Hofker 1957
Genus ***GYROIDINOIDES*** Brotzen 1942 or ***HANSENISCA*** Loeblich & Tappan 1987
Gyroidinoides soldanii d'Orbigny 1826 and Genus ***GYROIDINA*** d'Orbigny 1826
Gyroidina? regularis

Note: The taxonomy of *Gyroidina / Gyroidinoides / Hansensica* is a complex issue. The forms identified here are simple morphologies which would fit the *Gyroidina / Gyroidinoides* concepts of Culver (1988) who assigns them mostly to environmental zones between 500m and 1,000 m, but recording them consistently through his bathyal and abyssal zones. Similarly van Marle considers them fairly good bathymetric indictors occurring from about 400 m to his lowest sample at 2,120 m. Jones (1994) follows a simple species concept for *G. soldanii*, similar to that used here, and ranges this species from 300 to 2,000 fm (549 to 3,660 m). Other *Gyroidina* species have ranges within these limits.

INTEGRATION OF THE NEW STRATIGRAPHIC DATA INTO THE GEOLOGICAL MODEL

The basal Early Oligocene age indicated by the biostratigraphy and Sr dating is considered reliable as three groups of microfossils, most precisely nannofossils, all suggest the same age, and this is corroborated by an age derived from strontium dating of benthic microfossils (abbreviated here as 321.2 MYBP). The environment of deposition cannot be determined so precisely, in spite of many analogs to faunas from about 3,000 meters water depth in the open oceans, The regional geological setting of the Bagelen Beds includes shallower Eocene and Oligocene sediments occurring to the north, northeast, south and west[1], suggesting a semirestricted basin is more likely than a deep shelfedge facing the open ocean. Studies of such semirestricted deep basins in Indonesia (Umbgrove, 1949) shows they contain benthic water masses that cannot be directly correlated with the open ocean. It is therefore possible the true palaeobathymetry was much shallower, possibly as little as 1,000 metres. However this environment of deposition is much deeper than the previous implied shallow marine settings based on microfaunal descriptions of photic larger foraminifera.

The detailed sedimentology of the Bagelen Beds is not known because of its extremely soft nature and thereby paucity of outcrops. The clay in the core is completely without bedding and has an irregular texture. Very few pebbles or coarse sand grains are

1. Only about 20 kms to the north is the basement edge of the Sunda craton, with marine transgression beginning in later Oligocene times (cf. Jubang-1, NCJ-B-1 & NCJC-wells). To the south Nanggulan & Gamping Barat both have shallow marine Middle and Late Eocene, to the northeast are shallow marine Early Oligocene sands in Rembang-1 near Semarang, and to the west, albeit a long way, are several locations of shallow marine Early Oligocene, around the Bayah Dome.

recorded (in contrast to the same unit in other cores about 25 kms to the south, at Langse and Sempor, report in prep.). The areal distribution of loose clasts and boulders of Eocene carbonates and conglomerates (square symbols on Figure 5) appears to match the distribution of Bagelen Beds claystones(solid circles on Figure 5). It was the distribution of these Eocene and basement derived boulders that was used by van Bemmelen (1937) to define his four terrains, yet all the terrains have poor outcrop and low relief (cf. the contours on Figure 6).

This geographic association suggests that the boulders of limestones, conglomerates and other basement derived lithologies, from a metre to tens of metres in size, are probably olistoliths in a slumped clay mélange. This interpretation implies stratigraphic reworking of shallow marine Middle and Late Eocene strata during Early Oligocene times. However, the size of the boulders and the setting suggests such reworking is more likely to have been the collapse of a submarine sedimentary shelf, rather than uplift and subarial erosion.

It is assumed that such boulders are concentrated in the mapped terrains by being hard and indurated, while the enclosing mass of soft claystone is very rapidly weathered and carried away.

Such an association of soft claystone with boulders of Middle Eocene limestone may also be seen about 10 kms due south of the Worawari / Bagelen area, in the upper reaches of the Kali Lukulo, including the Kali Gua location, famous for nummulitids (Figure 6). Here preliminary field work has found little outcrop in a low relief area, but with many scattered and often very large boulders of Middle Eocene limestone. The few outcrops of claystone not considered alluvium in this low-relief drainage area did not yield any microfossils. (However note that the clay matrix at Kali Gua / North Lukulo area has not been dated and this outcrop may correlate with the older pebbly mudstone at Kali Sana to the south, discussed on the next page).

If this interpretation of a soft clay olistostrome deposit is correct, it suggests a possible cause for the Sangiran Dome mud volcano 115 kms to the east (Figure 1). This extinct mud volcano at the heart of the Sangiran Dome has yielded many boulders, to over 2 metres, of Eocene limestone and polymict conglomerates (cf. van Bemmelen, 1949, p. 106). The setting for such xenoliths in a mud volcano has been problematic, the most recent account of Itihara et al. (1985) assumed Early Miocene clay drove the mud volcano, as it probably does in other parts of eastern Java (eg. Kuwu mud volcano 48 kms NE of Sangiran and others near Surabaya). In order for such young diapiric mud to include older, Eocene and presumed basal transgressive conglomerate boulders, an overthrusting fault was envisaged to bring such old lithologies up and over the buoyant claystone (Figure 7a). However such an interpretation is not supported by gravity data which shows no step-up in basement and only a very deep clastic depocenter in this area. An alternative explanation would be the presence of a facies as seen in the Jebeng core and Worawari area. Such a soft, under-compacted clay would be prone to form diapirs, and in doing so would carry its load of olistolith boulders to the surface (Figure 7b). One difference between the two sites is that at Worawari the limestone boulders are dominantly Middle Eocene (Ta), with traces of Late Eocene as mudstone (eg. W-2), but at Sangiran the boulders are mixed Middle and Late Eocene,Ta-Tb, carbonates (personal obs., and Sudijono, 1985).

It should be noted that other pebbly claystones are known in Central Java, the most significant being the short section of Kali Sana southeast of Karangsambung (25 kms south of Worowari and about 800 metres E-W along section, report in prep.). This outcrop contains Middle Eocene plankton in the clay matrix and is overlain by bedded Middle Eocene clays and turbidites yet includes boulders of Middle Eocene and older limestone, sands / conglomerates to several metres, and even mudstone clasts / slump sheets with Early Eocene planktonic fossils. The diapiric clay at Sangiran is more likely to correlate with the very soft, massive Bagelen Beds than the mudstone at Kali Sana as the latter is slightly indurated, mixed with bedded units (albeit strongly slumped and contorted) and therefore not as likely to develop into a diapir. Of course, the pebbly claystone at Kali Sana pre-dates both the Bagelen Beds and the Tb (Late Eocene) age of the limestone boulders ejected in the Sangiran mud volcano.

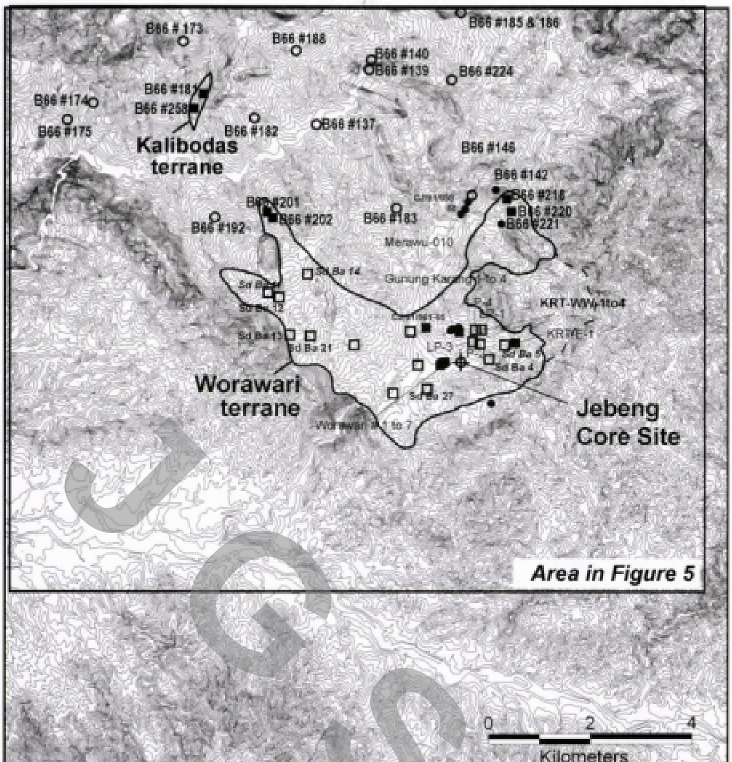
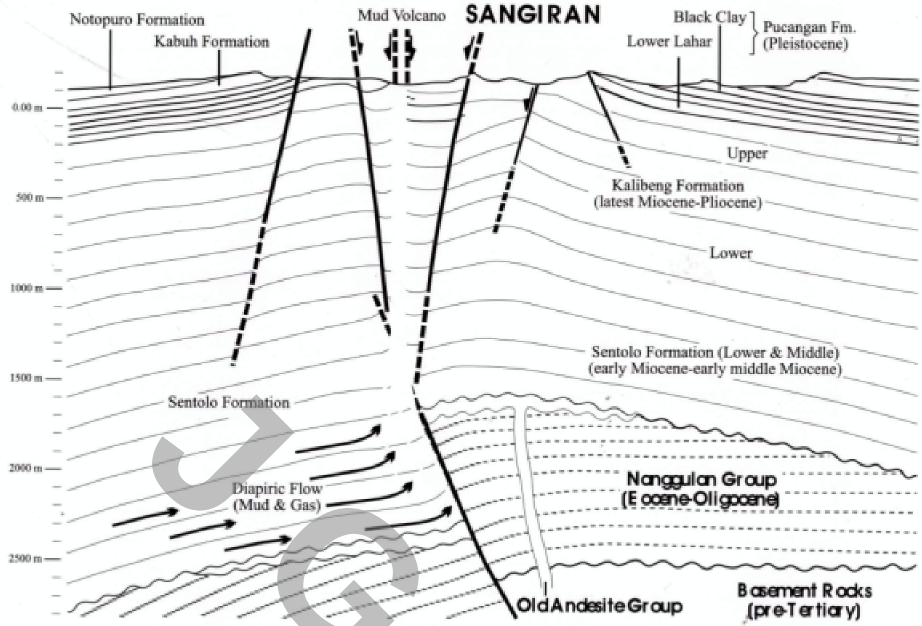


Figure 6. Topographic map of the Worawari area and the area around the north-eastern end of the Lukulo basement high. Note the "eocene" terranes are low relief with no sign of bedded hard limestone. Mapping shows Eocene limestone as very small, discontinuous outcrops



Firuge 7. (a) above: The Itihara *et al.* (1985)model for Sangiran mud volcano, slightly simplifed, based on feld work, but not supported by gravity data which shows no indication of high density basement, or change in basement level.

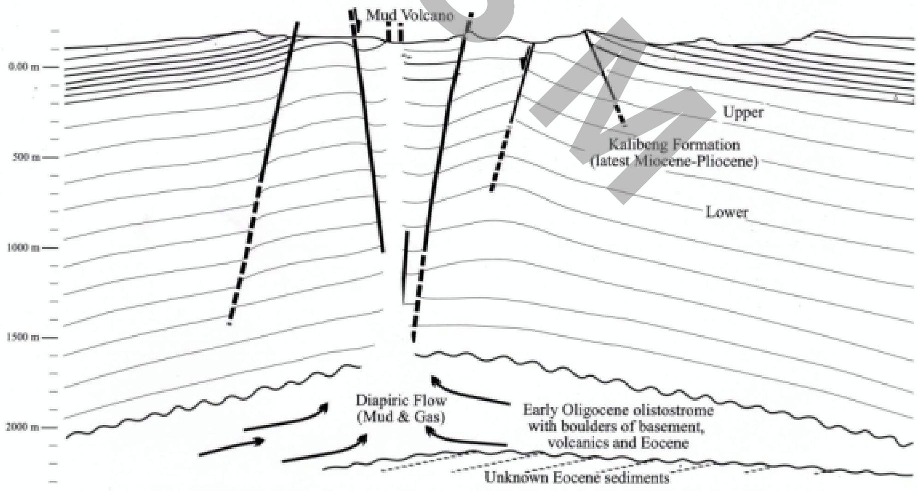


Figure 7. (b), below, is adapted to ft the possibility of Early Oligocene scaly clay olistostrome in the area. At the core of the dome focusing of fuids and gasses may rupture the overlying beds and allow some of the overpressured boulder-bearing clay to escape to the surface. No seismic data is available over the Sangiran Dome.

REGIONAL SETTING

The very deep marine environment of deposition of the Bagelen Beds contrasts both with the Eocene limestone blocks it contains, and the nearby and overlying Sigugur limestone. This limestone is found on the northern side of the Sigugur terrane of Bagelen Beds, 30 kms NW of Worawari, and is mapped as a shallow marine, reefal deposit mapped as over 3 kms by 1 km (van Bemmelen, 1937). If this limestone is roughly *in-situ* then it represents an enormous regression between Early and Late Oligocene times. The pebbly claystone Bagelen Beds mapped below the Sigugur Limestone contains general Eocene *Nummulites / Discocyclina* sandy limestone. The lower contact of the limestone is not seen. It is of course possible that the Sigugur limestone is an extremely large olistolith [and at the time of writing there is new evidence supporting this olistolithic origin and a mid- to later Early Miocene age, Lunt, in prep.]. This would be consistent with the environment of the overlying Early Miocene Merawu beds which are supposedly deep marine turbidites (ARCO, 1991, unpublished oil company report on the Kali Tulis section). However an olistolith of this size will not travel laterally very far and points to a severe topographic variation nearby.

As mentioned earlier, there is lack of precision in assigning a palaeobathymetry to the Bagelen Beds. Water depths of around 3,000 metres, as suggested by simple analog to modern faunas seem unreasonably deep for an area on or immediately flanking the Sunda Plate conposed of sialic crust.

Such water depths are currently found in the forearc basin south of Java, in the far-northern end of the Makassar Straits, and the area north of Flores to the east (Hamilton, 1979). These are areas that are located well off the Sunda Plate. Following Umbrgove (1949) we suggest that it may be invalid to use open ocean correlations for palaeobathymetry and a shallower depth, maybe as little as about 1,000 metres is possible.

The trough north of Lombok is also off the main Sunda Plate (cf. Figure 6 of Nugrahanto and Noble, 1997) and here water depths are currently as deep as 1,700-1,800 metres.There may be value in using the north Lombok area as an analog as seismic data has been published from this region by Matthews and Bransden (1995) and wells can be used to date sediments as old as Eocene. In this paper an earlier Oligocene compressional unconformity is noted (cf. Fold-outs 1 & 2 op.cit.) but considered a minor event in the region by these authors. Their seismic data shows this mid-Oligocene event to be currently at nearly 3 kms below sea level, covered by a thin wedge of distal Neogene sedimentary overburden.

In control wells in this area it is ambigous as to whether this unconformity was near base Oligocene or nearer mid-Oligocene times. This differentiation is important as ongoing work by us onshore Java can identify two major tectonic unconformities, one basalmost Oligocene and in mid-Oligocene times. Our interpretation of biostratigraphy suggests the near base Oligocene event is the largest and most widespread, and most probably the "mid" Oligocene seismic event as mapped by Matthews & Bransden. In this eastern area the greatest lithological contrast in the deep marine clays is seen at this event (see p. 503 op.cit. on the T34 to T36 transition).

We therefore think it is possible that the area from Worawari, probably Sangiran, and extending east to the Bali-Lombok trough underwent massive and rapid subsidence in basal Oligocene times. This produced water depths of possibly 2,000 metres - at least north of Lombok where the underlying crust is probably less buoyant.

It is also possible that the area of Bagelen is off the edge of the buoyant Sunda sialic plate and is underlain by mixed or mafic crust, with other areas, such as Nanggulan and Gamping Barat to Jiwo to the southeast, being on relatively buoyant sialic microplates. Such highstanding microplates are needed to explain the shallow to non-marine marine sediments found there in the Middle Eocene. Note that some parts of the deep area north of Bali-Lombok has Eocene reefal limestone, based on unpublished seismic data, and Eocene oils of lacustrine origin, all of which require a more extensive Eocene land mass, extending the concept of Sundaland further east and south than most current models suggest. Of course some of these southern and southeastern areas may not be a continuous land area, but highs over microplates with lows between.

There are many questions and possible objections to this simple regional model, such as why pebbly clays, slumping and reworked Eocene olistoliths are not yet observed in north Bali or Lombok? However a robust palaeogeographic reconstruction for the Early Oligocene is not yet possible due to the scarcity of good data points of this age in the region. The hypothesis above is recognised as weak, but is offered only as a starting point. At the very least it is considered an important deviation from, and hopefully an improvement on, the current mapped account, where the Bagelen Beds are considered transgressive Eocene, with shallow marine faunal listings.

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APPENDIX 1

Entry for Bagelen Beds in Marks (1957) Stratigraphic Lexicon of Indonesia.

BAGELEN BEDS (Formation) (Bagelen lagen). Eocene

VERBEEK (R.D.M.) (1892). *Nat. Tijdschr. Ned. Indie* : 134-135.

Marine conglomerates, quartz-sandstone, marls and clays. Limestone lenses with corals and larger foraminifera.

Name is obsolete

Type locality: Worawari, residency Bagelen, Serayu Mnts., N part of Central Java. Geographic distribution: Type locality only.

Diagnostic fossils: *Nummulites javanus* (Verbeek), *N. bagelensis* (Verbeek), *N. djogjakartae* (Martin), *N. nanggulani* (Verbeek), *N. vredenburgi* (Provale), *Discocyclina javana* (Verbeek), *Borelis* sp.

References: Rutten (L.M.R.) (1927), p. 74; Bemmelen (R.W. van) (1937), p. 10; Bemmelen (R.W. Van) (1949), p. 104.