CRETACEOUS ROCKS OF MISOOL ARCHIPELAGO, INDONESIA

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ABSTRACT

Cretaceous rocks of Misool Archipelago are exposed mostly on the southern part of the main island of Misool and its adjacent islets. The rocks belong to the upper part of Lelinta Formation, Facet Limestone Group (Waaf Formation and Gamta Formation), Fafanlap Formation (Yabatano Member) and lower part of Daram Formation. The age of the rocks ranges from Aptian to Maastrichtian based on their fossil content. The lithology of each formation is redescribed herein.

The results show that almost the whole formations contain macrofossils such as molluscs and microfossils (foraminifera). The Gamta Formation (the oldest) is Late Berriasian to Middle Cenomanian in age based on the occurrences of *Ptilorhynchia* sp., *Proclydonophora* sp., *Rotularia* sp., *Buchia* sp., *ammonite gen. et sp. indet.*, coral *indet*., and trace fossils. Early Cretaceous is also indicated by the presence of *Hibolithes gamtaensis*, *H. miosensis*, *Duvalia* spp., and *Belemnopsis jonkeri*. Waaf Formation (Middle Cenomanian to Early Campanian) contains rich globigerinid and other microfossils, trace fossils, large *Inoceramus* up to 70 cm in length with oysters attached to it, and *Prochlydonophora* sp. But, this bivalve is very difficult to sample. The upper part of the Waaf Formation contains abundant microfossils, probably indicating a bathyal environment. Fafanlap Formation and its Yabatano Member contain micro and macrofossils such as *Inoceramus misoliensis, I.* (*Cordiceramus*) *paraheberti*, *I.* (*C.*) cf. *pseudoregularis*, *I.* (*Selenoceramus*) *sufflatus* and *I. haani*, *Durania wanneri*, and burrows indet. *Micraster* and *Hemiaster* were difficult to sample, and so were minor coral and bryozoan. *Inoceramus* spp. which are found in the lower part of Fafanlap Formation indicate a Middle Campanian age. The microfossils range up to Maastrichtian. It can be concluded that the age of Fafanlap Formation is Late Santonian up to Late Maastrichtian and at least Late Maastrichtian for the Yabatano Member. Based on the assemblage of microfossils reported by previous workers, the age of the Daram Formation in the lower part can be assumed as Late Maastrichtian.

Biostratigraphic correlation of Lower Cretaceous in Indonesian Archipelago based on microfossils promising for the islands of Rote, Timor, Seram, Buru, Buton, the eastern, central and south arms of Sulawesi, Halmahera, New Guinea and perhaps Obi and eastern Kalimantan. In the upper Cretaceous, inoceramid bivalves are more common and are closely related to those of New Guinea and Madagascar.

Cretaceous of the Misool Archiprelago is the most difficult part to correlate within Indonesia based on microfossils at present, but is promising in the future study. The microfauna of Misool is closely related to that of the Emscher Marl of Westfalen in Europe. The foraminifera also resemble those of the Seweer Beds in the European Alps. The Early Cretaceous of the upper part of the Lochambel Beds of Spiti, India with the *Neocosmoceras-Distoloceras* Assemblage is probably correlatable with the upper part of the Lelinta Formation of Misool. In Misool, however the latter is dominated by belemnites even though similar in rock facies (chert-bearing beds). The inoceramid species from Misool, e.g. *Inoceramus* cf. *bererensis*, *I.* (*Cordiceramus*) *paraheberti* and *I.* (*C.*) cf. *pseudoregularis* are closely similar to those found in Madagascar, some perhaps being conspecific, and in both area indicating a Middle Campanian age.

Key words: Misool Archipelago, Cretaceous, Lelinta Formation, Gamta Formation, Waaf Formation, Fafanlap Formation, Daram Formation, inoceramids, belemnites, foraminifera

SARI

Di Kepulauan Misool, batuan yang berumur Kapur tersingkap hampir seluruhnya di bagian selatan pulau utama dan pulau-pulau kecil di sekitarnya. Batuan-batuan tersebut termasuk ke dalam bagian atas Formasi Lelinta, Kelompok Batugamping Facet (Formasi Waaf dan Formasi Gamta), Formasi Fafanlap (Anggota Yabatano), dan bagian bawah Formasi Daram. Umurnya berkisar dari Aptian sampai Maastrichtian berdasarkan fosil yang dikandungnya.

Hasil penelitian menunjukkan bahwa, hampir seluruh formasi berumur Kapur tersebut mengandung fosil makro, misalnya moluska dan mikro (foraminifera). Formasi Gamta (tertua) berumur Berriasian sampai Cenomanian Tengah berdasarkan keberadaan Ptilorhynchia sp., Proclydonophora sp., Rotularia sp., Buchia sp., amonit gen. et sp. indet., koral indet., dan fosil jejak. Satuan-satuan yang berumur Kapur Awal juga ditandai oleh keberadaan Hibolithes gamtaensis, H. miosensis, Duvalia spp., dan Belemnopsis jonkeri. Formasi Waaf (Cenomanian Tengah sampai Awal Campanian) mengandung globigerinid yang melimpah dan fosil mikro lainnya , fosil jejak, Inoceramus berukuran besar mencapai panjang 70 cm dan banyak ostrea Prochlydonophora sp. yang menempel pada katupnya. Tetapi, pemercontohan Prochlydonophora sp. ini sulit dilakukan. Bagian atas Formasi Waaf mengandung fosil mikro yang menunjukkan aspek lingkungan laut dalam (bathyal). Formasi Fafanlap dan Anggota Yabatano mengandung fosil mikro dan fosil makro seperti Inoceramus misoliensis, I. (Cordiceramus) paraheberti, I. (C.) cf. pseudoregularis, I. (Selenoceramus) sufflatus dan I. haani, Durania wanneri, dan fosil jejak (burrows indet.). Pemercontohan Micraster dan Hemiaster sangat sulit dilakukan, begitu juga dengan fosil koral dan briozoa. Jenis Inoceramus spp. yang ditemukan di bagian bawah Formasi Fafanlap menunjukkan umur Campanian Tengah. Fosil mikronya mempunyai kisaran umur sampai Maastrichtian. Dengan demikian, dapat disimpulkan bahwa umur Formasi Fafanlap adalah Campanian Tengah sampai Maastrichtian Akhir, sedangkan Anggota Yabatano berumur paling tidak Maastrichtian Akhir. Berdasarkan kumpulan fosil mikro hasil penelitian penulis-penulis terdahulu, umur bagian bawah Formasi Daram juga disimpulkan Maastrichtian Akhir.

Korelasi satuan-satuan batuan Kapur di Kepulauan Misool dengan daerah-daerah lain di Indonesia berdasarkan fosil mikro sulit dilakukan sekarang, mungkin untuk masa mendatang. Fosil mikro di Kepulauan Misool mirip dengan yang ditemukan di Emscher Marl dari Westfalen di Eropa. Fosil foraminifera juga mirip dengan yang terdapat di Seweer Beds di Alpin Eropa. Kapur awal di bagian atas Lochambel Beds dii Spiti, India dengan kumpulan Neocosmoceras-Distoloceras kemungkinan dapat dikorelasikan dengan bagian atas Formasi Lelinta di Misool, tetapi di Misool fosilnya didominasi oleh belemnit, walaupun batuannya berfasies sama (lapisan-lapisan yang mengandung rijang). Jenis Inoceramida Misool, seperti Inoceramus cf. bererensis, I. (Cordiceramus) paraheberti and I. (C.) cf. pseudoregularis, mirip dengan yang ditemukan di Madagaskar, bahkan beberapa jenis sama, dan kedua daerah ini berumur Campanian Tengah juga.

Kata kunci : *Kepulauan Misool, Kapur, Formasi Lelinta, Formasi Gamta, Formasi Waaf, Formasi Fafanlap, Formasi Daram, inoceramida, belemnit, foraminifera*

INTRODUCTION

In general, very little detailed work has been done on the stratigraphy and paleontology of the Mesozoic rocks of Indonesia. Most workers before the seventies referred to compilations by van Bemmelen (1949) and Marks (1956;1957) which had been used as the most common source of geological information. For Misool Archipelago a slightly more detailed investigation on the Mesozoic lithostratigraphy and biostratigraphy has been done compared to other parts of Indonesia. Another factor that has led to the lack of detailed information about the rocks of that age is that they have long been regarded as generally lacking in economic prospects.

The Mesozoic marine biota of Indonesia is widespread, and very diverse, because the Indonesian Archipelago is composed of different tectonic fragments (terranes) which have been brought together by subduction and collision. The study of these tectonic theories of the eastern part of Indonesia has been carried out by various workers, amongst others Katili (1973,1980, 1989), Hamilton (1979), Pigram and Panggabean (1984), Simandjuntak (1992), Simandjuntak and Barber (1996), Hall (1996), Metcalfe (1996), and Sukamto (2000) . The Tethyan Sea which existed between the Australian and Asian Plates produced a very complex faunal association after collision. On one hand, part of the Pre-Tertiary fauna and flora of Indonesia is of Cathaysian origin, whereas on the other Gondwanan.

The Cretaceous sedimentary rocks of the Misool Archipelago comprise carbonate and clastic sediments and were deposited in shallow to deep marine environment. Figure 1 shows the distribution of Cretaceous rocks in Indonesia and the setting of the Misool Archipelago discussed in this paper.

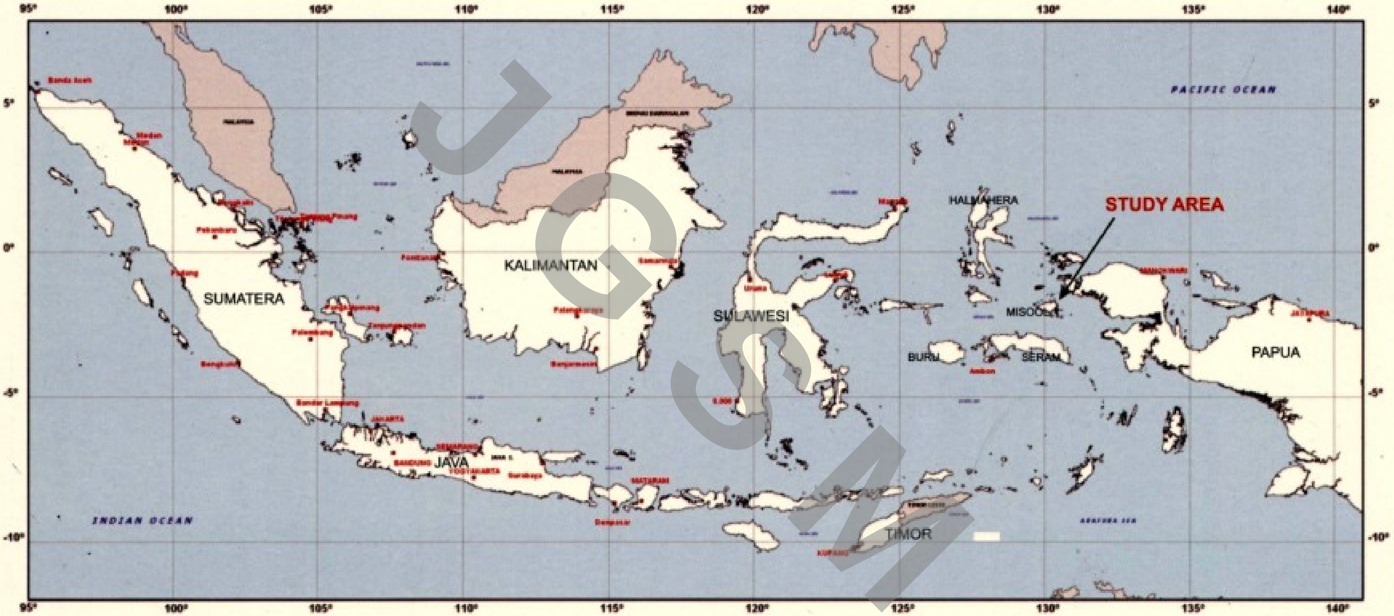

Figure 1. Geography of Indonesia Archipelago and location of the study area (Misool Archipelago)

METHOD

The Cretaceous system of the Mesozoic era is not studied comprehensively in Indonesia. Misool Archipelago is the only place where Cretaceous rocks are well exposed bearing almost complete stages (Berriasian to Maastrichtian). This paper is a summary what is known of these Cretaceous marine biota of the eastern part of Indonesia, based on the latest data collected by the senior author and those of the previous workers.

PREVIOUS STUDIES

The following summaries of works carried out by previous researches in particular those with report of the Cretaceous rocks are included in this part of study. They are considered to be the basic background for the future workers in the area.

Verbeek (1900) mentioned the occurrence of Cretaceous formation in the southern part of the Misool Archipelago near Lelinta which contained belemnites and regarded as an extension of Taliabu and Mangole Islands to the west (see also Martin, 1907).

Weber (1902) studied the geomorphology of the area and reported the presence of ammonites and belemnites as well as other fossils of Late Cretaceous age.

According to Boehm (1904) the similarity of the various species to those from the European Permian to Cretaceous, indicates that there had been a sea connection from the west right through Asia across the region of the present day of Himalayas. Uhlig (1910) found *Belemnites gerardi* group that was probably of Oxfordian to Neocomian age, but with some uncertainties.

Wanner (1910) divided the sedimentary rocks into ten units with ages ranging from Carnian to Upper Cretaceous.

Boehm (1924) discussed the fauna of Late Cretaceous rocks distributed in the main island of Misool and islands east of Lelinta as far as the Daram Island. The rocks, mainly marl, contain *Inoceramus* spp., rudists, irregular echinoid, small ostreas, and a few ammonites (*Pachydiscus* sp.). Foraminifera were also found. He called the unit the *Inoceramus-Radiolites* marl. Boehm also agreed with Wanner's opinion that the Cretaceous of Misool was closely related to that of Scaglia and Biancone in the southern Alps.

Rutten (1927) believed that Misool was an island belonging to New Guinea, connected to the latter by a shallow submarine platform and that the fauna had positive Papuan aspects.

Heinz (1928) revised the inoceramids described by Boehm (1924) from the Cretaceous of Fafanlap, Yabatano, and Yillu III Islands. He considered all the inoceramid species to Senonian age. He could not prove the Maastrichtian age which Boehm had accepted for the inoceramids in those areas.

Stolley (1929) discussed the Misool Neocomian of the Facet Limestone which contained *Hibolithes subfusiformis* Rasp., *Duvalia dilatata* Blainv., *D. lata* Blainv., and *Belemnopsis tanganensis* Futt. In 1934, Stolley corrected Weber's work in assigning Tithonian and the Early Cretaceous to the Lilinta Clays and *Inoceramus* Marl.

Umbgrove and Weber (1935) believed that continuous sedimentation from Jurassic to Early or Late Cretaceous persisted in Misool as well as in Timor, Seram, Buru and eastern Sulawesi, although local breaks in the Lower Cretaceous might exist.

Umbgrove (1938) pointed out that there is no unconformity between Jurassic and Cretaceous (see also Arkell, 1956).

Vogler (1941) in his discussion of the Jurassic and Cretaceous of Misool, compiled the stratigraphy of the area based on the result of the study of previous workers (Wanner, 1910; Boehm, 1904, 1924; Stolley, 1929; Krumbeck, 1934), and a stratigraphic column of the island was drawn.

Marks (1957) recognized 14 units of Mesozoic rocks in Misool ranged from Upper Triassic to Upper Cretaceous, with an unconformity between Upper Triassic and Lias.

Stevens (1965) reviewed the Jurassic and the Cretaceous belemnite faunas of the Indo-Pacific Region and he emphasized that the Indonesian belemnite sequences matched approximately those of the New Zealand.

Froidevaux (1974) regarded Misool Island as the northern flank of an ESE plunging anticlinorium. The stratigraphy of this area was believed to be complete from the Triassic to the present. He also compared the Misool sediments with those of Seram, stressing similarities especially in the Facet (Cretaceous) deposit and the presence of tuffaceous beds in both areas.

Skwarko and Hasibuan (1989) reviewed the literature on the larger marine invertebrates in the Cretaceous of Indonesia in which important fossils are listed. The cephalopod which number over 70 genera and species of which less than a third have been compared with the overseas forms. It is stressed that except for the most recently described forms, most generic and specific determinations are needed for revision. Much more work is needed on the local Cretaceous fossils before paleobiogeographic reconstructions are possible.

Hasibuan (1991) studied the stratigraphy and paleontology of Mesozoic of the Misool Archipelago.

REGIONAL GEOLOGY

The geological mapping of the Misool Archipelago was carried out by a joint party of Geological Survey Institute (formerly GRDC), Indonesia, and Australian Geological Survey Organisation (AGSO) (formerly BMR), Australia. They have produced a geological map of the archipelago at a scale of 1:250.000 (Rusmana *et al*., 1989). Distribution of the Cretaceous rocks on the Misool Archipelago is shown in Figure 2. The results of this study will contribute to a better understanding of the lithology and their fauna and geological history of this part of Indonesia which bears most complete sequences of Mesozoic strata and will be useful as a reference section to the adjacent areas.

Tectonic evolution, stratigraphy, geological history based on surface mapping of Indonesia have been studied by Visser and Hermes (1962), Hamilton (1979), Katili (1973, 1980, 1989), Pigram and Panggabean (1984), Simandjuntak (1992), Simandjuntak and Barber (1996), Hall (1996), Sukamto (2000), and Metcalfe (1996) on Cretaceous rocks. Figure 3 shows the relation of the early evolution of Cretaceous rocks of Gondwanaland, Laurasia, Pangea, and the Tethys Sea (Sukamto, 2000). The development of Pre-Tertiary tectonics in Indonesia comprises the tectonic convergence lasted since Paleozoic in western region, and tectonic divergence developed during Mesozoic in eastern region (Simandjuntak, 1992). Both regions have different geological affinities in terms of lithological characters, stratigraphy and tectonics. The Cretaceous rocks of the Misool Archipelago were deposited in ± 17° South Latitude (Panggabean *et al*., 2007). Paleogeographic recon-struction of the Southeast Asian terranes for Late Jurassic to Late Cretaceous are shown in Figure 4 (Metcalfe, 1996). Panggabean *et al*. (2007) propose a modification on the reconstruction of the paleolatitude and tectonic evolution during the Late Jurassic through Cretaceous-Paleocene in the Indonesian Archipelago (Figure 5).

DISCUSSION

A stratigraphic column of Paleozoic to Mesozoic rocks of the Misool Archipelago is shown in Figure 6, while Cretaceous rocks is presented in Figure 7.

Gamta Formation

The oldest Cretaceous unit in this area is the Gamta Formation of Facet Limestone Group which typified of which the type locality is located on Gamta Island, south of Misool Island (Pigram *et al*.; 1982a,b). The formation consists of thickly bedded limestone in the lower part interbedded with thinly bedded light greenish calcareous shale beds in the upper part (Plate 1, Figure 1). The limestone is calcilutite in which ca. 30 m above the base, interbeds of chert (Plate 1, Figure 2) or chert nodules are found (Plate 1, Figure 3). The beds generally dip northeast at low angles.

Pigram *et al*. (1982a,b) estimated the thickness of the formation at about 80 m, whereas Simbolon *et al*. (1984) calculated about 262 m. The present work however, regards that its thickness is not more than 100 m. The only sedimentary structure observed in this formation are unspecified microbioturbation and wavy bedding surface. This formation is distributed in the Gamta Island, Kalig Island, Mo Island, and Cape of Moncol. The contact with the underlying Lelinta Formation is gradual from shale to true limestone of the Gamta Formation. The upper boundary is taken at the incoming of reddish brown sandy limestone beds which are more common in the overlying unit. The lower and the upper boundaries with the underlying and overlying unit are regarded as conformable.

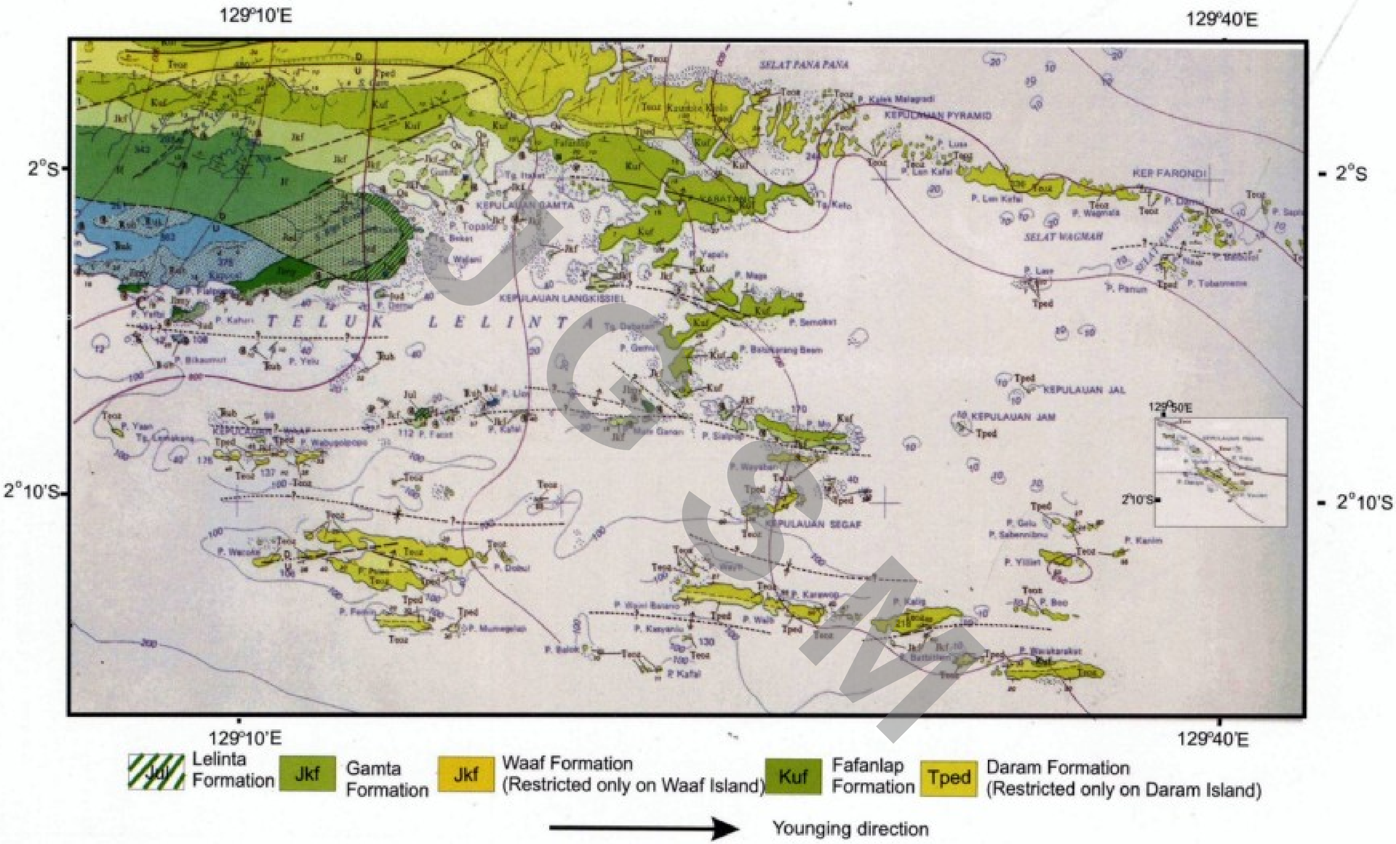

Figure 2. Geological map of the southern part of the Misool Archipelago where Cretaceous formations are mainly distributed and exposed (modified from part of Rusmana *et al.*, 1989, 1:250.000 scale).

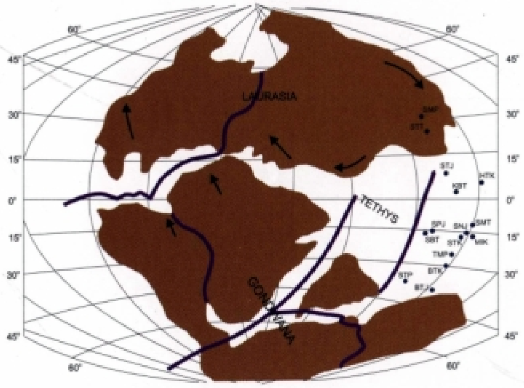

Figure 3. Pre-Tertiary palaeogeographic of terranes in Indonesia, correlated with the position of the Laurasian and Gondwanaland in Jurassic time (after Sukamto, 2000).

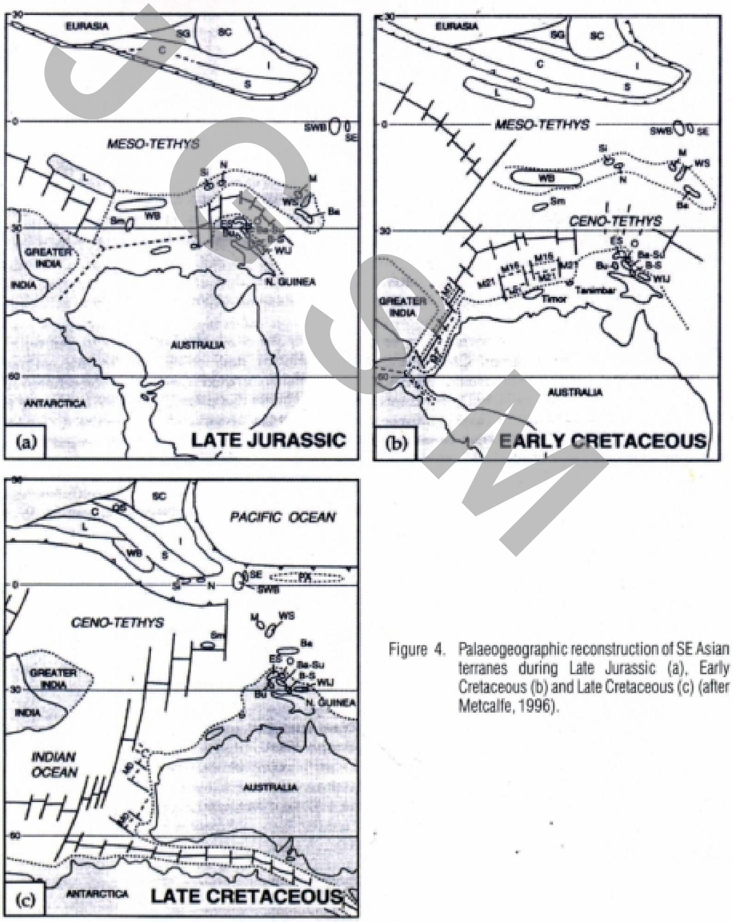

Figure 4. Palaeogeographic reconstruction of SE Asian terranes during Late Jurassic (a), Early Cretaceous (b) and Late Cretaceous (c) (after Metcalfe, 1996).

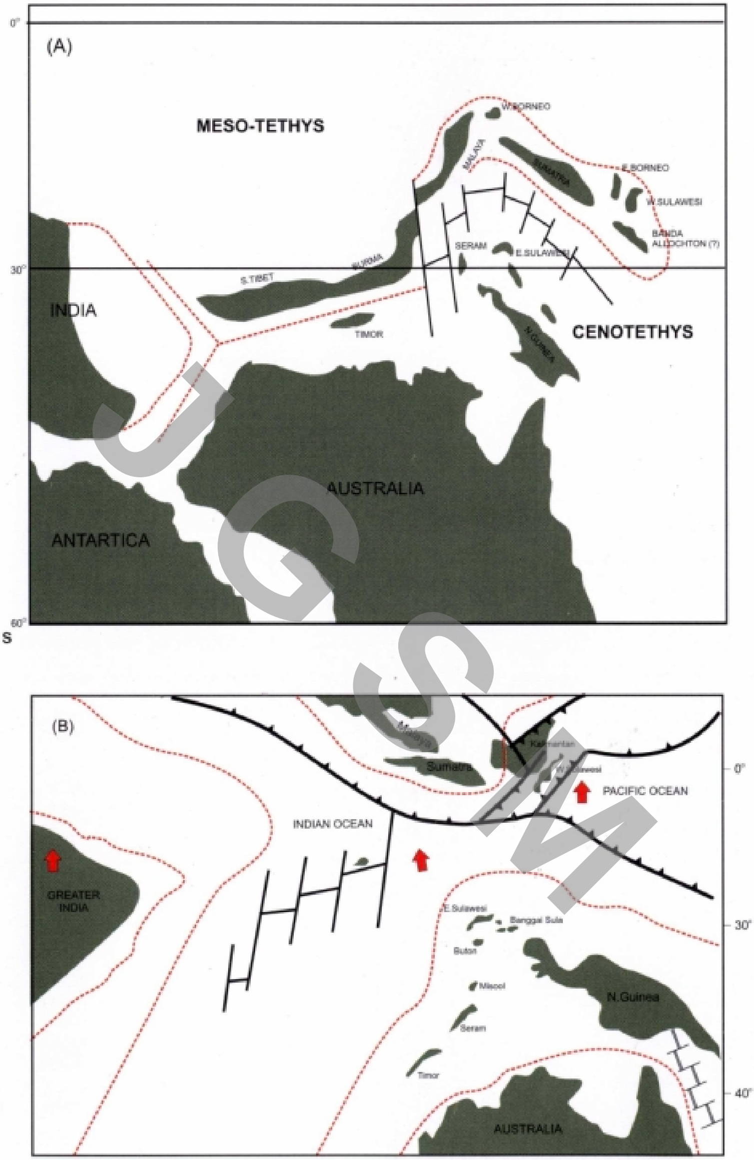

Figure 5. Palaeogeographic reconstruction of the Indonesian Archipelago during (A) Late Jurassic - (B) Cretaceous - Early Tertiary (Panggabean et al. 2007).

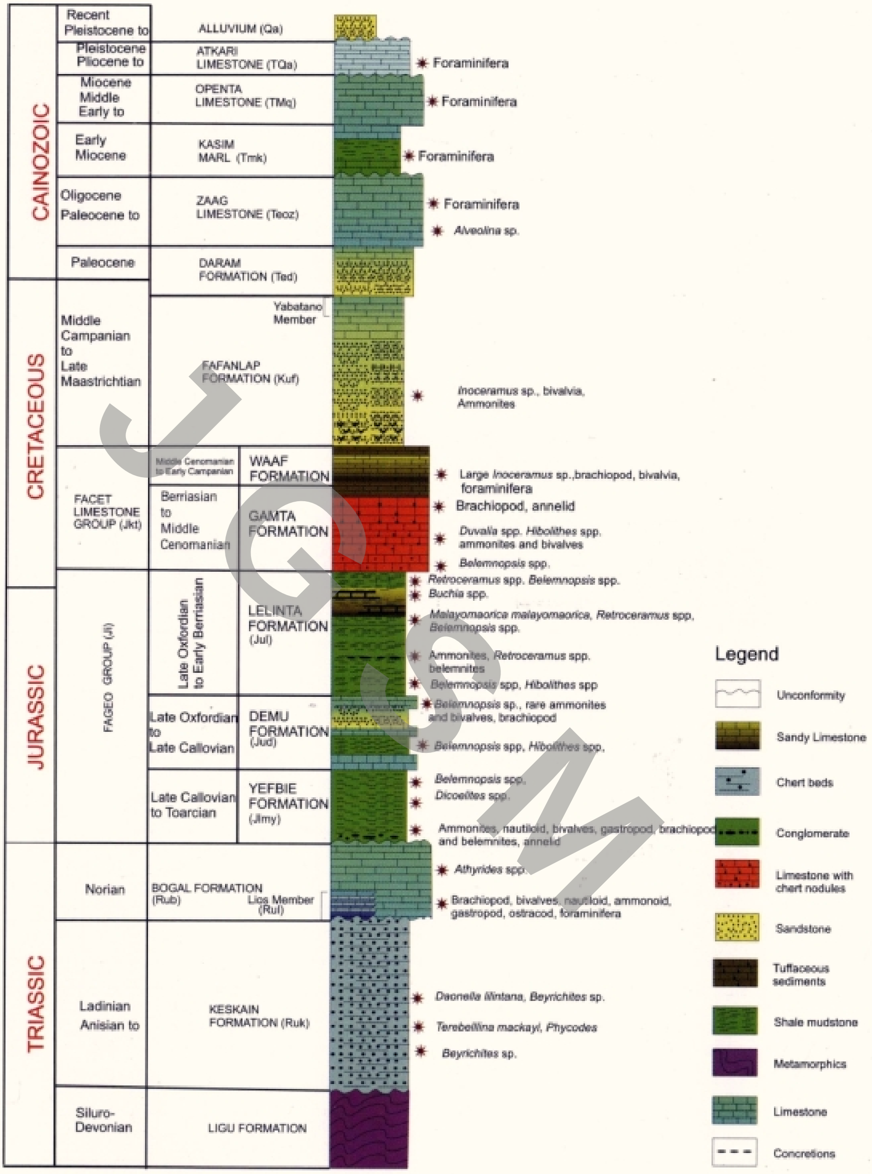

Figure 6. Palaeozoic to Cainozoic stratigraphic column of Misool Island, Eastern Indonesia (modified after Hasibuan, 1991).

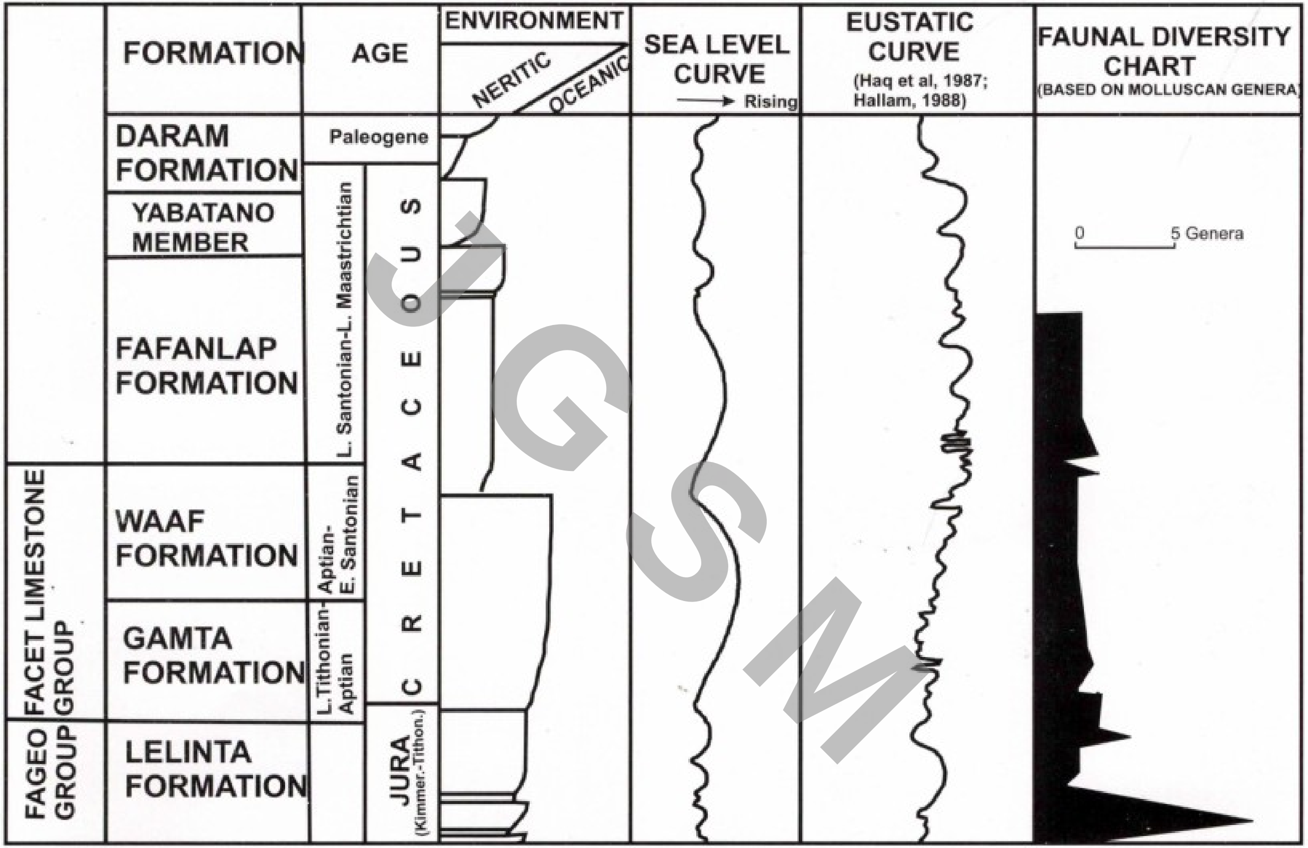

Figure 7. Stratigraphic column of Cretaceous formations, showing environment, sea level curves, eustatic curves and faunal diversity curve for the Misool Archipelago (Hasibuan,1991).

PLATE 1

Figure 1. Thickly bedded limestone interbedded with thinly bedded light greenish calcareous shale of Gamta Formation.

Figure 2. Calcilutite with interbeds of cherts of Gamta Formation.

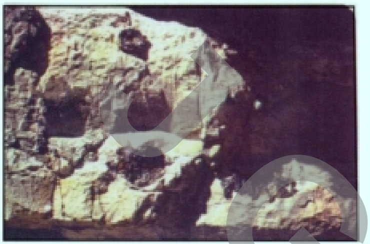

Figure 3. Calcilutite and chert nodules in Gamta Formation.

Figure 4. Thinly bedded tuffaceous calcilutite and calcareous mudstone of Waaf Formation.

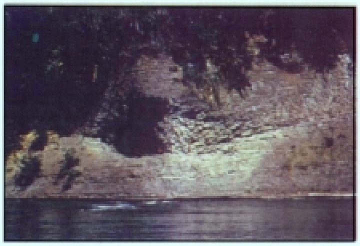

Figure 5. Large scale crossbedding (megaripple/ hummocky crosbedding) in Fafanlap Formation.

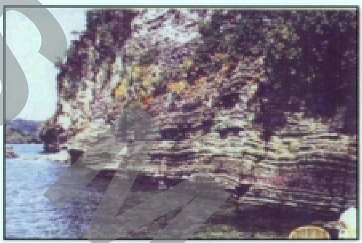

Figure 6. Thinly bedded oolitic limestone with some intercalated bioclastic beds of Yabatano Member, Fafanlap Formation.

Figure 7. Close up of Yabatano Member, Fafanlap Formation.

Figure 8. Wellbedded medium to coarser grained calcareous quartz sandstone and sandy limestone of the Daram Formation.

The formation contains brachiopods such as *Ptilorhynchia* sp., *Proclydonophora* sp., *Rotularia* sp., *Buchia* sp., ammonit gen. et sp.indet., coral indet., and trace fossil. The presence of *Belemnopsis stolley* at the base makes its last appearance and is of Late Tithonian age (Challinor, 1989). Vogler (1941) regarded that the "globigerina bed" in the upper part was Aptian in age before the incoming of *Globotruncana* in the overlying unit. Thus, the age of Gamta Formation is Late Tithonian to Aptian.

Waaf Formation

Waaf Formation is to include the rest of the "upper Facet Limestone" of previous workers, the upper member of Facet limestone Group, the lower boundary of which is placed at the top of the underlying Gamta Formation (Pigram *et al*.; 1982a,b). Its type locality is on Waaf Island, south of Misool Island. In the lower part, it consists of interbedded laminated reddish brown limestone and minor whitish sandy limestone. The limestone is also shaly and in some places interbedded with minor reddish chert beds and/or nodules (Plate 1, Figure 4). In the upper part the formation becomes more generally reddish/brownish in colour, and the limestone are coarser and highly tuffaceous. The volcanic source probably lies to the north where volcanics of the same age have been penetrated in a petroleum exploration well (Pigram *et al*., 1982a,b). Simbolon et al. (1984) reported the thickness of the formation reached 164 m, but this work calculate it is only 80 m, and so does Pigram *et al*. (1982a,b). The Waaf Formation is seen to have conformable contact with both the underlying Gamta Formation and the overlying Fafanlap Formation.

The formation contains rich microfossils such as foraminifera, trace fossils, and large Inoceramus up to 70 cm in length with oysters attached on it, *Prochlydonophora* sp. The bivalve is very difficult to sample. The upper part of the Waaf Formation contains abundant microfossils, probably indicating bathyal environment, but lacks *Nodosaria misolensis* Vogler which is a Santonian to Campanian marker. Thus, the age of Waaf Formation is Late Aptian to possibly Early Santonian.

Fafanlap Formation and Yabatano Member

Fafanlap Formation with its Yabatano Member in the upper part, is named after Fafanlap Village on Fafanlap Island, and Yabatano Member after Yabatano Island where this member is exposed (Pigram *et al*., 1982a,b).

This formation consists of shaly limestone (more common in the lower part) interbedded with dark grey tuffaceous calcareous silty shale, tuffaceous maroon in colour. In the upper part, the formation is more shaly mudstone, interbedded with calcareous siltstone pink to maroon in colour. The Yabatano Member at the top of the formation consists entirely of thinly bedded oolitic limestone, with some intercalated bioclastic beds. The thickness of the formation is about 200 m (Pigram *et al*., 1982a,b, and this work), while Simbolon *et al*. (1984) estimated up to 460 m. The Yabatano Member is probably not more than 50 m thick.

Fafanlap Formation is exposed along the south coast to the west up to the headwaters of Fageo River and to the east to Yabatano, Semoket, Mo, Warakaraket Islands and their islets.

The formation contains foraminifers such as (Vogler, 1941), but this work, *Cadosina* spp. is regards belonging to tintinina. This work also collected some macrofossils such as *Inoceramus misoliensis, I.* (*Cordiceramus*) *paraheberti*, *I.* (*C.*) cf. *pseudoregularis*, *I.* (*Selenoceramus*) *sufflatus* and *I. haani*, *Durania wanneri*, and burrows *indet*. *Micraster* and *Hemiaster* were difficult to sample, and so were minor coral and bryozoan. The *Inoceramus* spp. which are found in the lower part of Fafanlap Formation indicate a Middle Campanian age. They are found together with some microfossils Vogler (1941) which range in age to Maastrichtian. The underlying Waaf Formation is Aptian to Early Santonian in age. Waaf Formation underlies the Fafanlap Formation conformably. It can be concluded that the age of Fafanlap Formation is Late Santonian to Late Maastrichtian and at least Late Maastrichtian age for the Yabatano Member.

The depositional environment of the Fafanlap Formation was lower neritic zone shallowing to epineritic (Simbolon *et al*., 1984), whereas Pigram *et al*., (1982a,b) regarded it as bathyal and was radically changing to shallow marine deltaic environment. The large scale crossbedding (megaripple/hummocky cross-stratification) (Pigram *et al*., 1982a,b; Simbolon *et al*., 1984; Hasibuan, 1986) (Plate 1, Figure 5) was probably caused by occasional disturbance by large scale waves such as tsunami. Yabatano Member (Plate 1, Figure 6) was probably deposited under littoral (shoal) conditions not far from the coast line. A close up view of the Yabatano Member is shown in Plate 1, Figure 7.

Daram Formation

The type locality of the Daram Formation is on Daram Island, east of Misool Island (Pigram *et al.*, 1982a,b). It consists of alternating carbonaceous shale and very fine sandstone of volcanic origin with laminated beds in the lower part. The middle part consists of medium to coarse grained sandstone and thinly bedded siltstones. The sandstones become thicker and coarser towards the top and are rich in volcanic fragments. The upper part of the formation consists of marl and calcareous siltstone, with some limestone intercalations. The top of the formation is dominated by well bedded limestone (Plate 1, Figure 8). The estimation of the thickness of the Daram Formation is about 50 m. However, Simbolon *et al.*, (1984) also recognized it along the Ilum and Elba Rivers on Misool Island and estimated about 534 m thickness. Pigram *et al.*, (1982a,b) regarded the lithologically similar outcrops on mainland Misool as belonging to the Tertiary sequences (Zaag Formation). This issue is beyond the scope of this study, and the Daram Formation treated here is restricted to that distributed in the Daram Island. The formation is underlain by Yabatano Member conformably.

Pigram *et al.*, (1982a,b) regarded this formation was of the Tertiary age, however Simbolon *et al.*, (1984) recognized an assemblage of microfossils showing a Late Cretaceous age in the lowest part of the formation. It can be assumed that the Daram Formation is Late Maastrichtian to Early Paleogene.

Biostratigraphy and Correlation

The lower Cretaceous of Misool Archipelago is mostly defined by the presence of belemnites and the sequence is regarded as continuous up from Jurassic. However, the contact between the Jurassic and Cretaceous in Sula Islands is believed to be an unconformity (Surono and Sukarna, 1984; Supandjono and Harjono, 1984). Cretaceous foraminifera from Misool are also found in Rote, Timor, Seram, Buru, Buton, the eastern, central and southern arm of Sulawesi, Halmahera, New Guinea and perhaps Obi and eastern Kalimantan (Umbgrove, 1938). In the upper Cretaceous, inoceramid bivalves are more common and are closely related to those of New Guinea and Madagascar.

Regional and international correlation based on macrofossil evidence of the Cretaceous of Misool is difficult to perform due to insufficient number of such fossils in the beds of that age in this island. However, this can be overcome by employing macrofssils which are abundantly available for this purpose. However, we should wait for this opportunity. Fortunately, belemnite biozonation of the Jurassic to Cretaceous of Papua New Guinea is identical with those of eastern Indonesia (Challinor, 1990).

The microfauna of Misool is closely related to that of the Emscher Marl of Westfalen in Europe (Wanner, 1910; Boehm, 1924). The foraminifera also resemble those of the Seweer Beds in the European Alps (Umbgrove, 1938).

The Early Cretaceous of the upper part of the Lochambel Beds of Spiti with the *Neocosmoceras-Distoloceras* Assemblage (Krisna *et al.*, 1982) probably correlates with the upper part of the Lelinta Formation of Misool, but in the latter it is dominated by belemnites even though of similar rock facies (chert-bearing beds).

The inoceramid species from Misool, e.g. *Inoceramus cf. bererensis, I.* (*Cordiceramus*) *paraheberti and I.* (*C.*) *cf. pseudoregularis* are closely similar to those found in Madagascar, some are perhaps conspecific, and in both area and indicative of Middle Campanian age.

Faunal diversity very much depends on a complex of environmental factors such as paleogeography, climate, tectonism and sea level changes. In the case of Cretaceous fauna of Misool, consideration of changes in faunal diversity is of course very much related to the analysis of sea-level changes (see also Figure 5).

Without neglecting effects of local tectonism, climate and paleogeography, the Tethys has played an important role in determining the level of Mesozoic faunal diversity and biotic influences from other parts of the world. Misool Archipelago is believed to have been not very different in Mesozoic paleolatitude from its present position. More precisely, it has been in its present position relative to the Australian continent since the Mesozoic (Dow and Sukamto, 1986; Audley-Charles, 1988), although some writers still express different opinion (*e.g.* Pigram and Panggabean, 1984). This may lead to the assumption that climate and paleogeographic factors did not greatly affect faunal diversity. Nevertheless, these factors should not be neglected (Stevens, 1980; 1985).

Most of the Cretaceous sediments show a deep water origin and are advocated for foraminiferal contents. However, in the Middle Campanian, the presence of inoceramids, foraminifera, and large-scale crossbedding may indicate a slight regression, although it is possible that the large-scale crossbedding has been caused by tsunami and thus probably has nothing to do with regression can not be ignored. With the lack of macrofossils in another part of the Cretaceous this approach can not be attempted, because sediment characters (calcilutite) indicate a deep water origin.

CONCLUSION

The environmental deposition of the Cretaceous rocks was deep marine, as suggested by calcilutite deposits with chert beds and nodules in the Gamta Formation. The overlying Waaf Formation although without any chert beds nor nodules is also dominated by calcilutite. The Waaf Formation is highly folded and faulted and also showing small slump structures.

In the early Campanian, a slight regression occurred and silty mudstone with large-scale crossbedding was deposited in conditions which were probably not deeper than continental shelf. In the lower part, inoceramids are found and although these are regarded as deep water by some authors, in Misool they probably lived in slightly shallower waters with moderately high energy. Upwards, the environment became shallower where limestone of the Yabatano Member was deposited in conditions which were probably as shallow as the continental shelf. Fine to coarse crossbedded sandstones of the Daram Formation were probably deposited in a neritic environment in Late Cretaceous time.

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