REEF FACIES OF THE WONOSARI FORMATION, SOUTH OF CENTRAL JAVA

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Abstract, The Limestones of the Wonosari Formation distributed to the south of Yogyakarta show excellent exposures for the study an Indonesian Tertiary reef model. The natural etchings of the outcrops in the field offer an opportunity to distinguish various facies of the carbonate rocks of this formation. Within the Wonosari Limestone the types of facies, which can be recognized include planktonic packstone-wackestone facies, packstone-rudstone facies, coral boundstone facies, grainstone-packstone facies, and algal-foraminiferal packstone facies. These facieses represent basinal toe of slope, reef slope, reef zone, surge channel to lagoonal sediments and back reef to shelf sediments.

INTRODUCTION

The Tertiary limestones, which are distributed between Parangtritis to the south of Yogyakarta and Pacitan in East Java, crop out over a large area and show excellent exposures. This area is well known as the Gunung Sewu (meaning "Thousand Mountains"), referring to the karst morphology expressions of pepino hills.

The first author of this paper has studied this area since 1991 in relation to the hydrogeology survey of the Wonosari area. Follow-up investigations of the carbonates in this area have been conducted since that time. The facies of carbonate rocks can be distinguished from the excellent natural etching of outcrops and have been confirmed by the study of polished slabs and petrographic work in the laboratory.

This study is still continuing and this paper is to be considered as a progress report especially referring to the western part of the area.

GEOLOGIC SETTING

Geologically, the Wonosari area belongs to the Southern Mountains, which is bounded by the Baturagung basin to the north and the Bantul graben to the west. The Tertiary sedimentation in the Baturagung basin started in Late Oligocene with deep marine volcaniclastic sedimentation.

STRATIGRAPHY

Surono and Sudarno I. (1988) Wartono R., Sukandarrumidi, and H. M. D. Rosidi (1995), and Sudarno (1997) have studied regional geology of this area. The general stratigraphic column of the Southern Mountains showed in Figure 1.

The oldest rock (Pre-Tertiary) in this area crops out in the surroundings of the Djiwo Hills in Bayat, North of the Southern Mountains. The rocks consist of phyllite, slates, schist, marble, and other metasediment. Sedimentary rocks of the Wungkal-Gamping Formation of Eocene age unconformably overlie the metamorphic rocks. This formation consists of sandstones and limestones containing abundant large foraminifera such as *Nummulites* sp., *Discocyclina* sp., and *Pellatispira* sp. The Kebo-Butak Formation unconformably covers the Wungkal-Gamping Formation. This formation consists of tuffaceous conglomerate, sandstone and clay, which were deposited in Late Oligocene. Two formations cover the Kebo-Butak Formation, namely the Semilir Formation and the Nglanggran Formation.

The Semilir Formation of Early Miocene-Middle Miocene age consist of tuffaceous

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Key words: reef facies, depositional environment, model of the Tertiary limestone, Wonosari Formation.

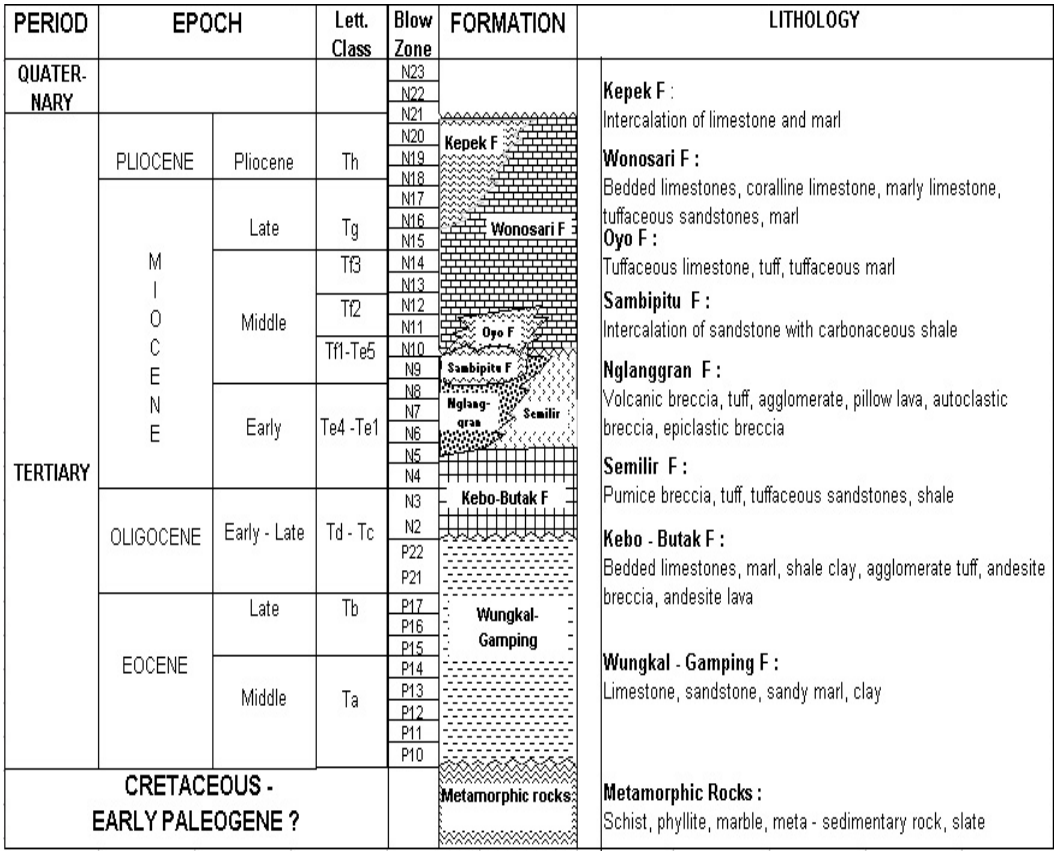


Figure 1. Stratigraphy of the Southern Mountains (after Sudarno, 1997).

sandstone, claystone, pumiceous pebbly sandstone, and pumice breccia. The Nglanggran Formation mainly consists of breccia, conglomerates, basaltic andesite intrusions, pillow lava and sandstone and is of the same age. The two formations are partly interfingering.

Overlying the Nglanggran and Semilir Formations are the Sambipitu, Oyo and Wonosari Formations. The Sambipitu Formation consisting of marine sandstone and claystone deposited during Middle Miocene. The Oyo Formation is a mixed marine-volcanic facies consisting of tuffaceous marl, clays andesitic tuffs and conglomeratic limestones. This formation is of Middle Miocene age and is interfingering with the lower part of the Wonosari Formation.

The Wonosari Formation, which is the main object of this study, represents a carbonate platform, deposited during Middle Miocene-Pliocene age. The upper part of this formation is interfingering with tuffaceous marls of the Kepek Formation.

CARBONATE FACIES TYPES OF WONOSARI FORMATION

Within the Wonosari Limestone, various facies types can be recognized, the recognition being mainly based on field observations and augmented by petrographic analysis. The following facies have been recognized:

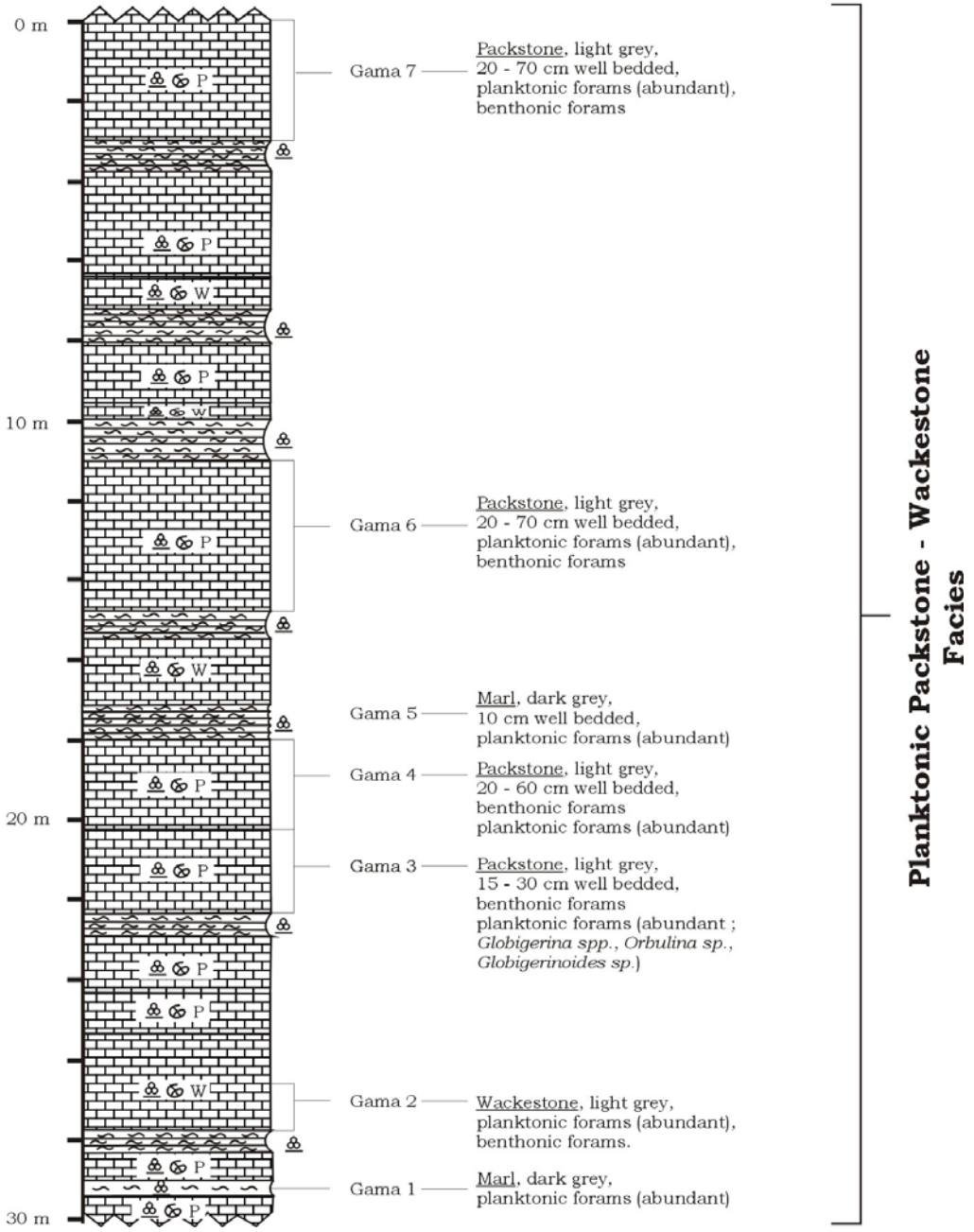
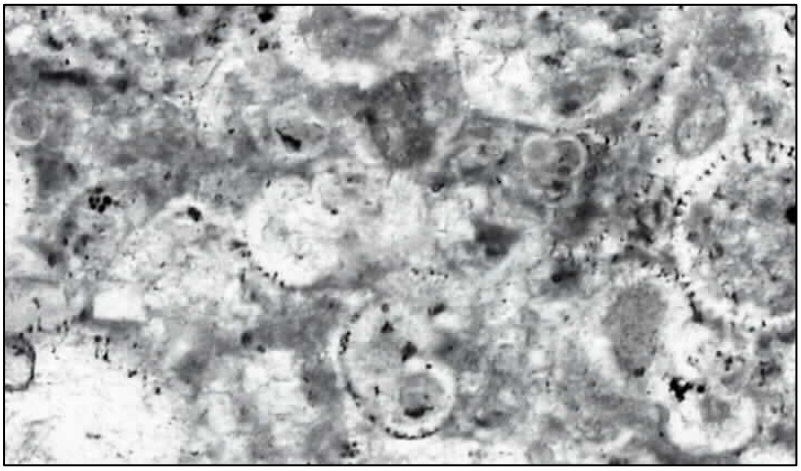


Figure 2. Measured section at Wanagama shows the planktonic packstone-wackestone facies.



(a)

(b)

(c)

Figure 3. Photographs of planktonic packstone – wackestone facies: (a) thin section of Gama 7 *(see previous figure)*, shows abundantly of planktonic foraminifera test, (b) Outcrop of planktonic packstone – wackestone facies, shows well bedded packstone interbedded with thin bedded marl in Kepek Village, (c) Well package of packstone – wackestone in Luweng Serpeng.

a. Planktonic Packstone-Wackestone Facies

Visually this facies is easily recognized in the field from its lithology and type of bedding. The rocks mainly consist of packstone-wackestone containing abundant of *Globigerina spp*. with subordinate benthonic and larger foraminifera (*Lepidocyclina* sp., *Cycloclypeus* sp.). The sediments are usually well bedded and thin (10-30 cm), but sometimes up to 60 cm thick (see Figure 2 and Figure 3). The color is light grey to white. Bioturbation is common especially tracks of *Ophiomorpha* on the bedding surface are typical. Dark grey marl intercalations are common. The marls are thinly layered (2-10 cm) and contain planktonic foraminifera with small amounts of benthonic foraminifera. In some places the interbedded limestone shows channeling, lenticular layers and wedge-outs. Planktonic foraminifera are very abundant (up to 90%), consisting of *Globorotalia menardii, Globorotalia praemenardii, Globorotalia obesa, Globorotalia mayeri, Orbulina universa, Globigerinoides*

trilobus, Globigerinoides subquadratus, Globigerinoides altiaperturus, Globoquadrina altispira, Globoquadrina dehiscens, Globigerina bulloides, and *Globigerina venezuelana* (Middle Miocene age). Benthonics assemblages include *Bulimina* sp., *Nodosaria* sp., *Dentalina* sp., *Plectofrondicularia* sp., and *Epistominella* sp.

Intraparticle and interparticle porosity types are commonly observed in the planktonic packstone. Porosity analysis conducted on a Wanagama sample resulted in 27.89% and a permeability of about 273 mD.

b. Packstone-Rudstone Facies

This facies consist mainly of coarse grained, poorly sorted bioclastic packstone interbedded with thick-bedded coral debris rudstone. The packstone is coarse grained to extremely coarse grained, poorly sorted bioclastic, light grey to brownish, thin to thick bedded (30-50 cm), hard and compact (Figure 4 and Figure 5). Foreset cross bedding and intraformational truncations have been observed in this facies at the Semanu area, east of Wonosari.

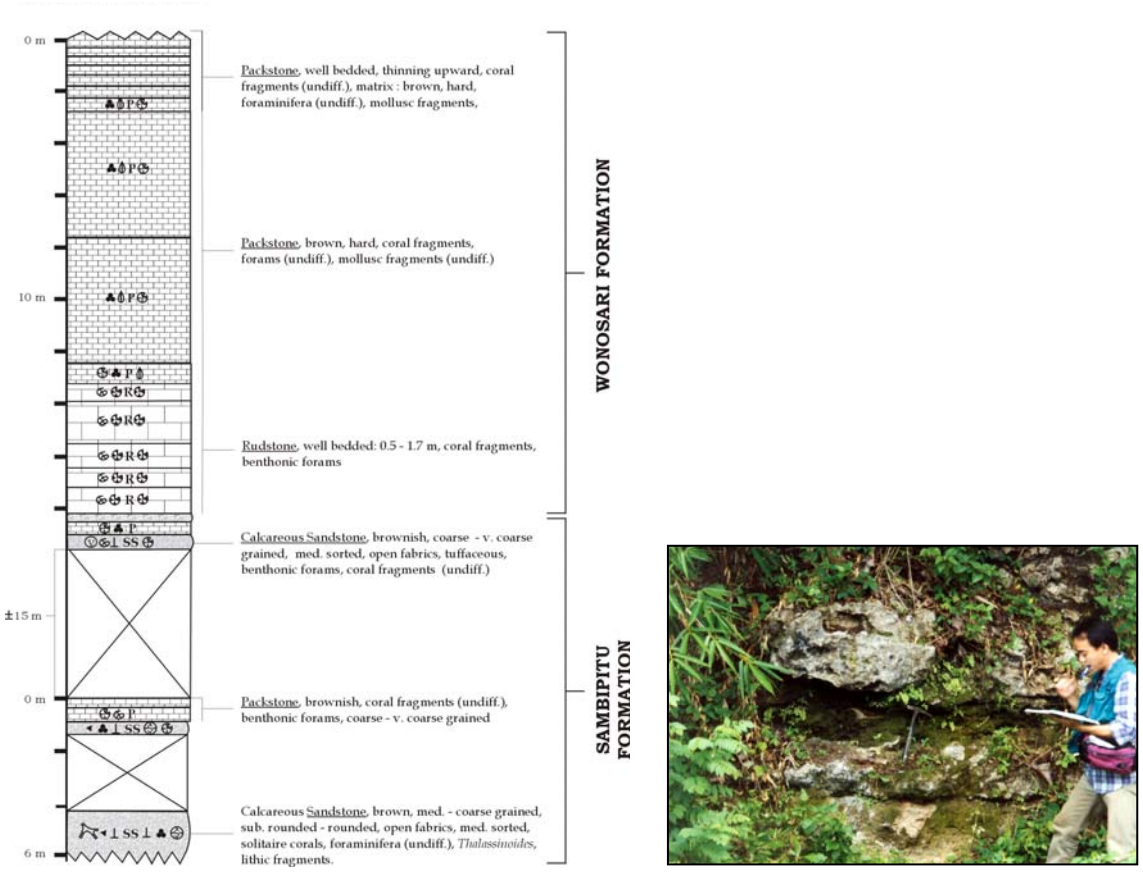


Figure 4. Measured section of Nawangan packstone-rudstone facies *(left)*, and outcrop shows packstone and rudstone interbedded with calcareous sandstone *(right)*.

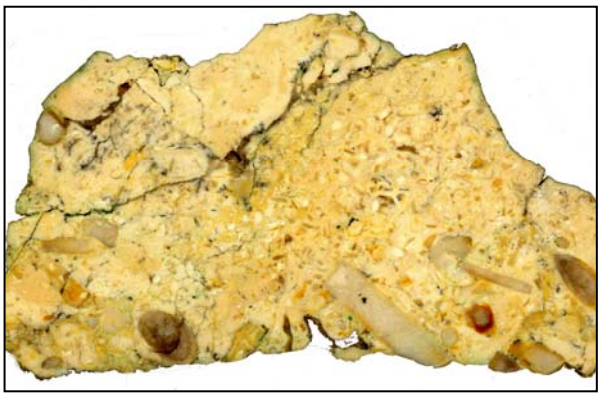


Figure 5. Polished slab of sampel from Sodong shows very coarse bioclastic grained packstone consisting of abundant large foraminifera, coral fragments, red algae, and echinoid spines.

Thin section examination of this rock taken from the Sodong area show coarse-grained poorly sorted bioclastic packstone, consisting of large foraminifera, red algae fragments, coral fragments, benthonic foraminifera, echinoid spines, and plankton. The large foraminifera tests are very large, consisting mainly of *Lepidocyclina* spp., and *Amphistegina* spp., with subordinate *Cycloclypeus* sp., *Heterostegina* sp., *Miogypsina* sp., and *Operculina* sp.

Thick-bedded rudstone (50 cm-2 m) are frequently present interbedded within the packstone sequence. These rocks are very dense and massive, containing massive corals and branching coral fragments. Porosity of this facies is of the intraparticle and interparticle types.

c. Coral Boundstone Facies

This facies consist of limestone, light colored, dense, massive, and non-bedded to poorly-bedded. The framework of these rocks comprises mainly corals, among them filled with mud containing large foraminifera, molluscs, and algae. Based on the type of corals, this facies can be distinguished into three sub-facies namely Framestone Sub-facies, Bafflestone Subfacies, and Bindstone Subfacies (Figure 6-Figure 8). These three sub-facieses are usually intermixed together and can not be separately mapped.

- Framestone Subfacies:

This subfacies consists mainly of massive head corals within a packstone matrix infilling the spaces among the coral framework. In several locations corals in growth position have been observed. Branching coral fragments are common found in this facies, as well as gastropods, pelecypods, and large foraminifera.

- Bafflestone Subfacies:

This subfacies consist primarily of branching corals, mostly as broken fragments, some are in growth position embedded in micritic matrix. Massive corals, platy corals, pelecypods, gastropods, worm tubes, onkolites, and red algae are commonly observed in this subfacies. The thin sections of the matrix of this rock from the Sodong area (Figure 8.c, and Figure 8.d) show abundant large foraminifera test consisting of *Lepidocyclina* spp., *Heterostegina* sp., *Amphistegina* sp., *Operculina* sp., *Cycloclypeus* sp. and *Miogypsina* sp. Besides these fossils considerable amounts of branching red algae fragments, echinoid, pelecypods, *Halimeda*, planktonic and benthonic foraminifera are found. Porosity of this facies are of the intraparticle, interparticle and moldic types. Porosity analyses of a sample from east of Gebang yielded 15.10%, and a permeability of about 0.07 mD.

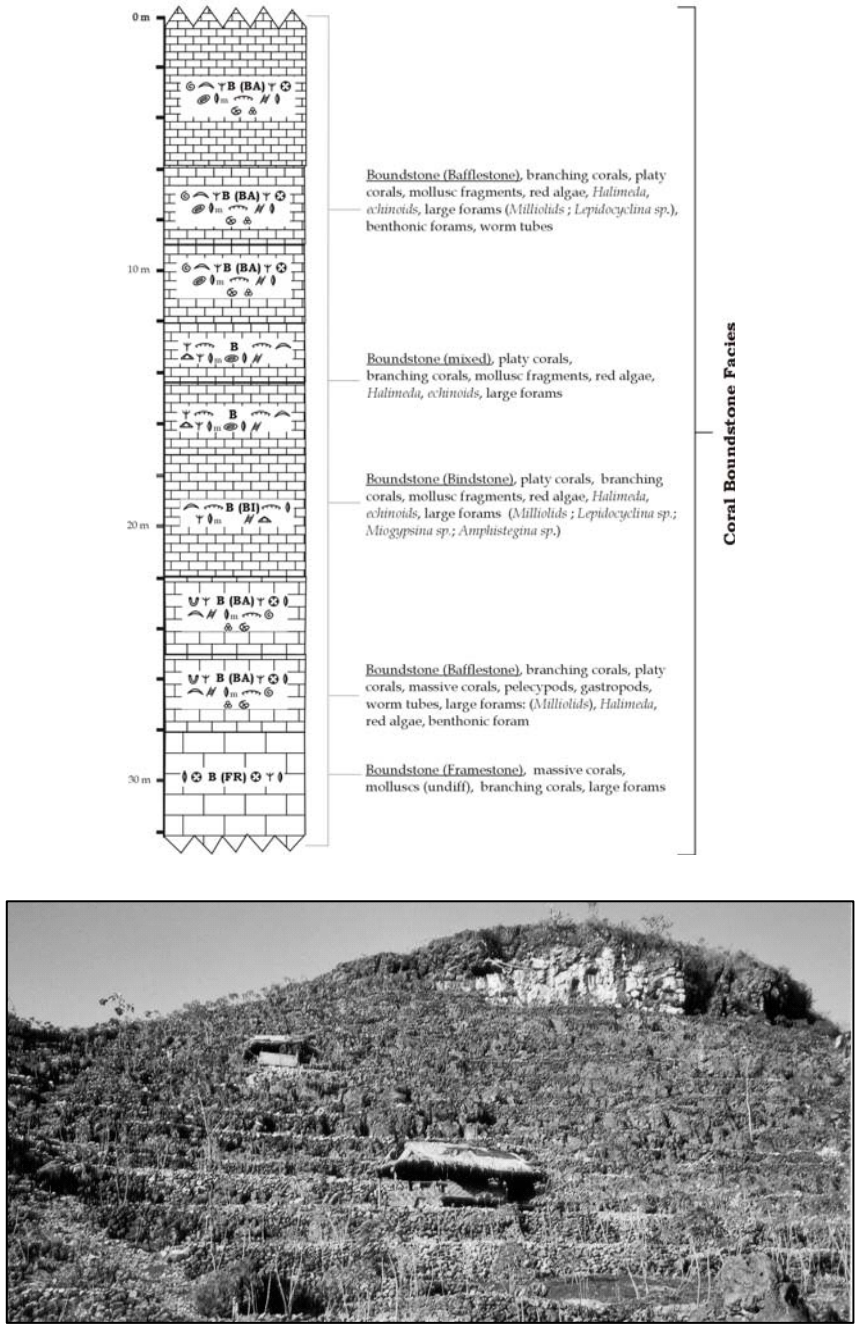


Figure 6. Measured section of boundstone facies in Sodong (*top*), and overview of boundstone outcrop in Sodong (*bottom*).

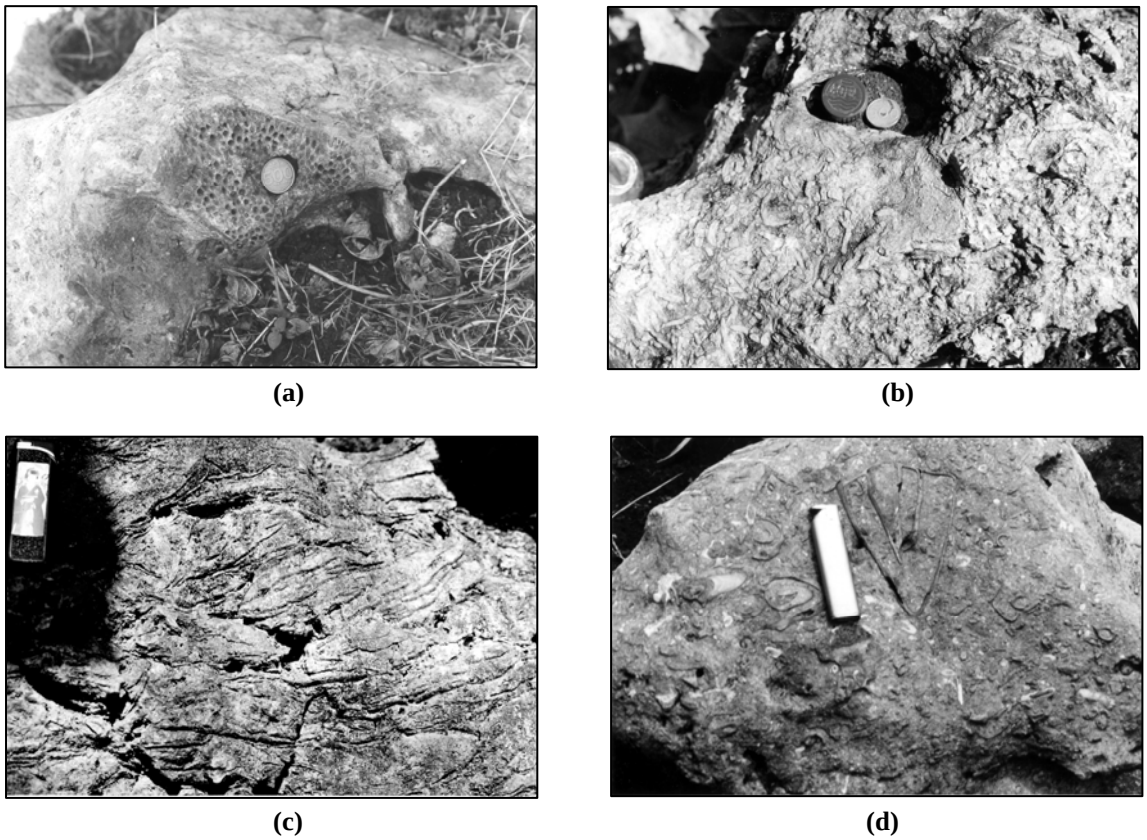


Figure 7. Outcrop photographs of coral boundstone in Sodong: (a) massive corals in growth position, (b) show natural etching of branching corals bafflestone, (c) natural etching of platy corals bindstone, (d) very clear etching of mollusc in mixed boundstone.

- Bindstone Subfacies:

This subfacies consists of platy corals, which are aligned parallel to the bedding or undulating. Within the platy corals framework is lime mud matrix containing large foraminifera and other bioclastic fragments. The thin section of these rocks from Sodong samples (see Figure 8.f) show platy corals, molluscs, large foraminifera *(Lepidocyclina* sp., *Miogypsina* sp., and *Amphistegina* sp.*)*, red algae, *Milliolids*, and platy algae (*Halimeda*) within the lime mud matrix.

Porosity of this facies is of the intraparticle, interparticle and moldic types. Analyses of a sample from Sodong yielded 5.99% porosity, and a permeability of about 0.03 mD.

d. Grainstone-Packstone Facies

This facies is represented by coarse grained, poorly sorted yellowish white to light grey grainstone to packstone. The rocks are well-bedded, thin-thick; showing wavy laminations, channel crossbedding with erosion surfaces at the base. Worm tubes and other bioturbation are common, and tracks such as *Thalassinoides* and *Rhyzocorallium* are typical. This facies is overlying a coral bafflestone, which was interpreted to represent storm sediment. The lower part of this facies is characterized by very thin

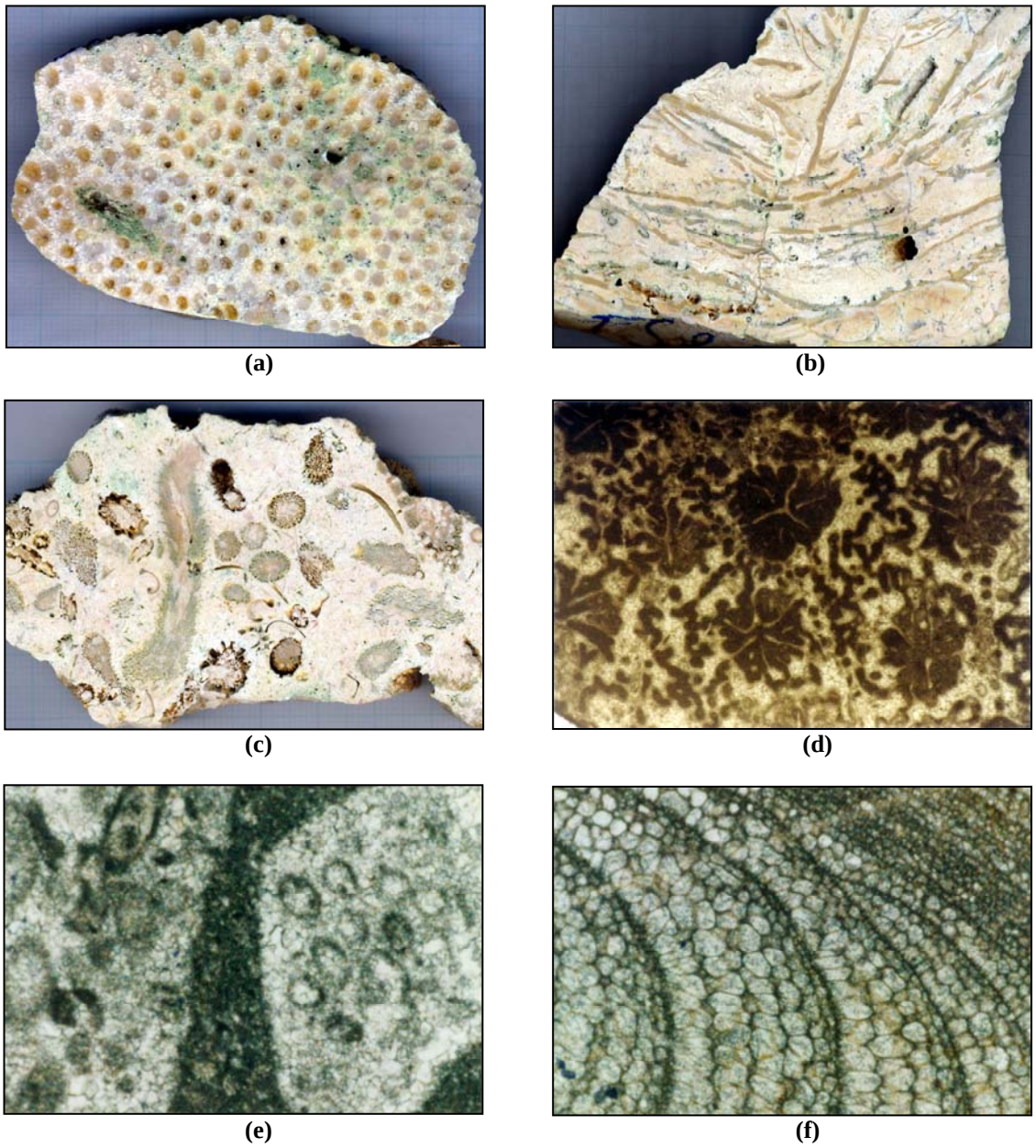


Figure 8. Photographs of coral boundstone polished slabs: (a) massive head coral, (b) platy coral from Sodong and, (c) branching coral bafflestone from Parangtritis. Photographs from thin sections: (d) transverse section of corals showing solid radial septa and recrystalized wall structure. The dark color is limemud matrix, sample taken from framestone (Parangritis), (e) well preserved *Halimeda* in matrix of bafflestone (Sodong), (f) red algae in matrix of bindstone (Sodong).

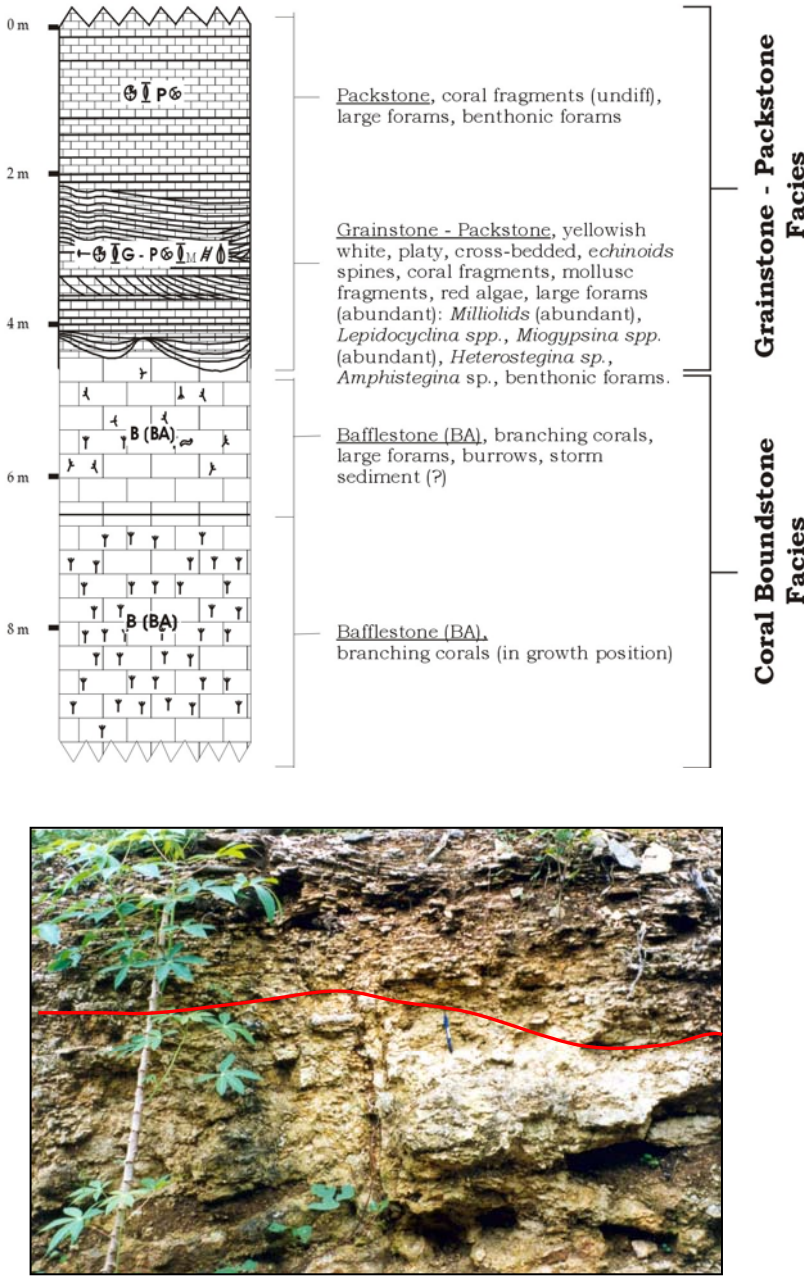
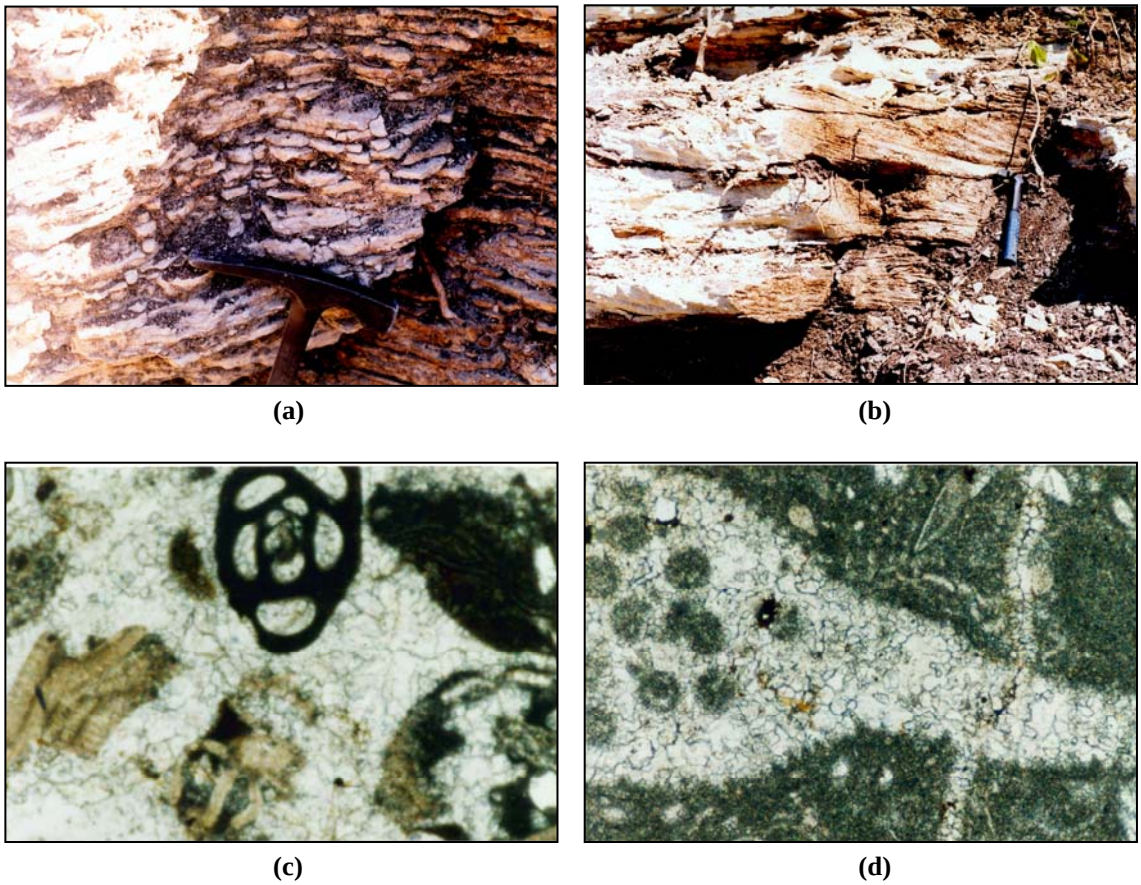


Figure 9. Measured section of Dempul surge channel sediments (*top*), and erosional surface between grainstone – packstone facies (upper solid line) with bafflestone below (*bottom*).

bedded (0.5-5 cm) grainstone-packstone while the upper part is dominated by thick bedded (20 cm-1 m) packstones. Gastropods, pelecypods shells and coral fragments are frequently present within the sequence. Some samples from this facies (Panggang-Dempul area) show bioclastic grainstone-packstone texture containing mostly large foraminifera and red algae fragments (Figures 9 and 10).

Foraminifera test consisting of *Milliolids*, *Miogypsina* spp., *Lepidocyclina* spp., *Heterostegina* sp., and *Amphistegina* sp. Molluscs, echinoid spines, planktonic foraminifera and *Halimeda* are observed in the thin sections.

Porosity of this facies is of the intraparticle, interparticle, and moldic types. Samples from Panggang and Gebang area show 7.98% and 13.60% porosity, with permeability of 0.06 and 0.20 mD.



(a) **(b)** **(c)** **(d)**

Figure 10. Photographs of outcrops and thin sections from Panggang–Gebang area show (a) the platy grainstone-packstone, (b) cross bedding of grainstone-packstone facies, (c) *Milliolids* in grainstone, and (d) *Halimeda* in the packstone.

e. Algal-Foraminiferal Packstone Facies

This facies consist of coarse grained to extremely coarse grained, poorly sorted bioclastic packstone, consisting mostly of onkolites and large foraminifera tests. The rocks are light grey to dark grey (weathered), poorly thick bedded (up to one m), very poorly sorted and often show undulatory to wavy bedding surfaces. Onkolites are commonly found in this facies, sub spherical in shape, sand to gravel size and showing crinkly laminations. In the Monggol area, this facies can be observed overlying the boundstone facies (Figure 11). In this location, the sizes of onkolites are extremely large (gravel size), occasionally loose and showing "gravel algal balls" (Figure 12).

Some thin sections from this facies have been analyzed and show mainly packstone texture. The bioclastic components consist mostly of algae such as onkolites, branching red algae and rhodolites.

Large foraminifera are commonly found such as *Lepidocyclina* sp., *Heterostegina* sp., *Amphistegina* sp., and *Operculina* sp. A small amount of mollusc fragments, benthonic foraminifera and echinoid spines are observed.

Porosity of this facies is of the intraparticle and interparticle types. Analyses of samples from Baron and Monggol ranged between 12.90-18.22%, with permeability of about 0.26-105 mD.

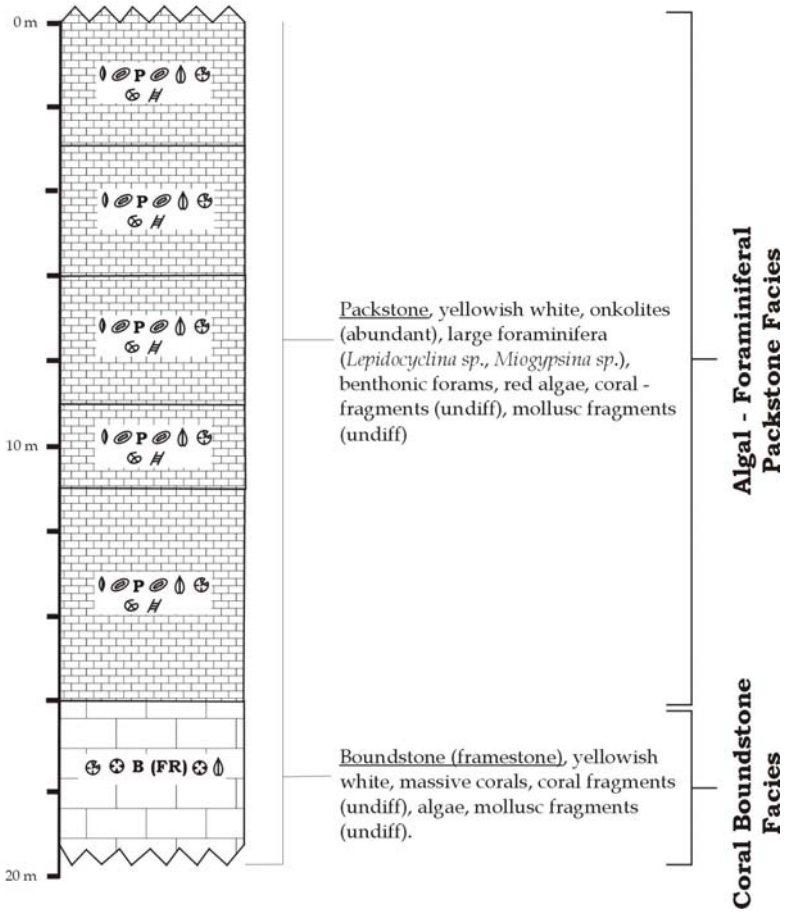


Figure 11. Measured section of algal-foraminiferal packstone in Monggol

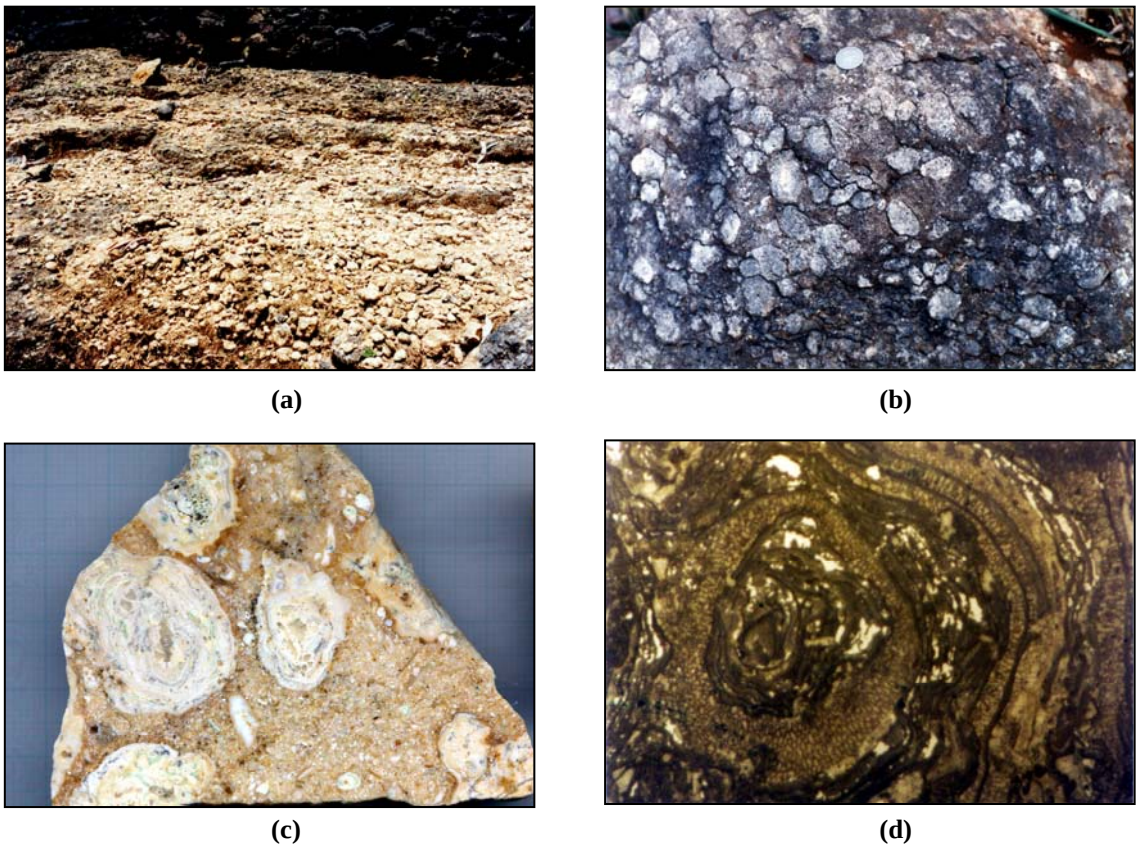


Figure 12. Photographs of algal-foraminiferal packstone show (a) algal ball of weathered packstone inTrewono, (b) natural etching of gravel sized onkolites in packstone from Tepus. Photographs of polished slabs, (c) onkolites in packstone bearing large foraminifera of Selogiri, (d) thin sections photographs of onkolites of Monggol.

DEPOSITIONAL ENVIRONMENT AND MODEL

Based on the identification of the facies types and their distribution, a depositional environment and model has been interpreted as follows:

a. Toe of Slope Sediments

This depositional environment is represented by the planktonic packstone-wackestone facies, thin to thick bedded and interbedded with marls. The packstone as well as marls are very rich in planktonic foraminifera (up to 90%) including *Globigerina* sp., *Globorotalia* sp., *Globigerinoides* sp., *and Orbulina* sp.. *Bulimina sp.* found in marl indicate a deeper, open marine environment. Bioturbation is common with typically tracks of *Thalassinoides.* The distribution of this facies is very wide spread and has been identified in several localities such as Wanagama,

Gading, Wonosari, Luweng Serpeng and around Ponjong (northern part of the Wonosari Formation). It seems that the Kepek Formation (Surono, et. al. 1992, and Wartono et. al. 1995), which is distributed in the Karangmojo-Kepek area belongs to this facies.

b. Reef Slope Sediments

This environment represented by thin to thick bedded packstone, coarse grained to extremely coarse grained and poorly sorted. Within this sediments, thick bedded coral rudstone are frequently present as interbeds, presumably as talus debris from the reef zone upslope. Coral and algae fragments are often found in these rocks. The large foraminifera are abundant and their sizes are very large. Foreset cross-bedding and intraformational truncations are observed in the sequence of this facies. Outcrops of this facies are well exposed in limited localities such as the Nawangan and Sodong areas (see Figure 4 and 5).

c. Reef Zone Sediments

Good exposures of the boundstone of the Wonosari reef are observed at the Sodong section. The reef zone depositional environment is represented by coral boundstone within the massive coral framestone, branching coral bafflestone, and platy coral bindstone are found. Generally these three subfacies are interbedded and often mixed laterally. The framestone of the lower part of the Sodong section presumably represented the reef front where the massive corals developed and intermixed together with branching corals, mollusks and foraminifera skeletal fragments. The bafflestone and bindstone of the Sodong section representing the reef crest to reef front where the branching coral and platy coral grew and were sedimented together with algae, molluscs, and foraminifera skeletals as well as *Milliolids* and *Halimeda* fragments transported from the back reef. The limemud and micrite accumulated within the space between the coral frameworks indicated that no strong wave activity occurred in the environment. This facies can be observed in several localities such as Girijati, Panggang, Sodong, and north of the Monggol area.

d. Surge Channel to Lagoonal Sediments

This depositional environment is represented by poorly sorted bioclastic grainstone-packstone facies. The rocks are well bedded, very thin to thick bedded, showing wavy laminations and chevron cross bedding. This facies is overlying the coral bafflestone facies, showing channeling with erosional surfaces at the base and interpreted as storm or tidal deposits (surge channel).

In the Dempul-Gebang area, the grainstone sediments are very rich in *Milliolids* and *Alveolinids*, as well as *Halimeda*, which indicates transport from the back reef lagoon to the fore reef slope. This facies can be observed in Gebang, Panggang and around Parangtritis in the western part.

e. Back Reef-Shelf Sediments

This depositional environment is primarily represented by algal-foraminiferal packstone, which shows thick and poor bedding to undulatory bedding surfaces. Algae fragments mostly of onkolites and branching red algae are commonly found. In some places such as Monggol and Jepitu area the onkolites are very abundant, in sand-gravel size, close fabric, and a conglomeratic appearance. The onkolite sediments in these locations are very thick and interpreted as algal ridge. Large foraminifera are also commonly found and occasionally shown embedding or encrustation of crinkly laminations of onkolites. This sediment is widely distributed to the south of the boundstone facies and is well observed in the Kepundung, Girikerto, Monggol, Baron, Tepus and Jepitu areas.

Based on the facies types, environment of deposition and the facies distributions, the model of the Wonosari reef can be described.

The Wonosari Formation was deposited as a rimmed shelf platform extending in a relatively east-west trend. The reef front or deeper part of the basin extending toward the north is represented by the planktonic packstone-wackestone facies of the toe of slope and packstone-rudstone facies of the reef slope. The benthonic foraminifera, especially *Bulimina* sp., indicate a deeper, open marine

environment of the toe of slope sediment.

The boundstone of the reef zone environment represents the reef front and the reef crest. In parts of the reef, tidal or surge channel and lagoons appeared to have been present. The channel transported sediments from the lagoon and brought back-reef skeletal debris northward in to the basin. To the south of the reef zone, the back reef to shelf sediments developed is represented by algal-foraminifera packstone. Algal ridges developed at some places on the shelf. A hypothetical cross-section showing facies relationship of Wonosari Limestone is shown on Figure 13, whilst a hypothetical carbonate sedimentation model is shown on Figure 14.

SUMMARY AND CONCLUSION

1. The Wonosari Formation is a Middle Miocene to Pliocene Carbonate Unit, exposed along Parangtritis to the south of Yogyakarta and Pacitan in East Java.
2. Several facies can be recognized within carbonate of the Wonosari reef, such as: Planktonic packstone-wackestone facies, packstone-rudstone facies, coral boundstone facies, grainstone-packstone facies, and algal-foraminiferal packstone facies.
3. Well-bedded planktonic packstone-wackestone facies, abundant in planktonic foraminifera, channeling, lenticular layers, wedge-outs and interbedded with marl, represent the toe of slope environment.
4. Packstone-rudstone facies representing the reef slope sediments are coarse grained, poorly sorted bioclastics, thin thick bedded, showing foreset cross-bedding and intraformational truncation.
5. Coral boundstone facies, massive, non-bedded to poorly bedded, represent the reef core. Three subfacies can be recognized in this facies: framestone subfacies, bafflestone subfacies, and bindstone subfacies. This subfacies represents the reef front to reef crest environment.
6. Grainstone-packstone facies, well bedded, thin to thick bedded, show wavy laminations, channel cross-bedding, and erosional surfaces. This facies represent deposits of the surge channel to lagoonal environment.

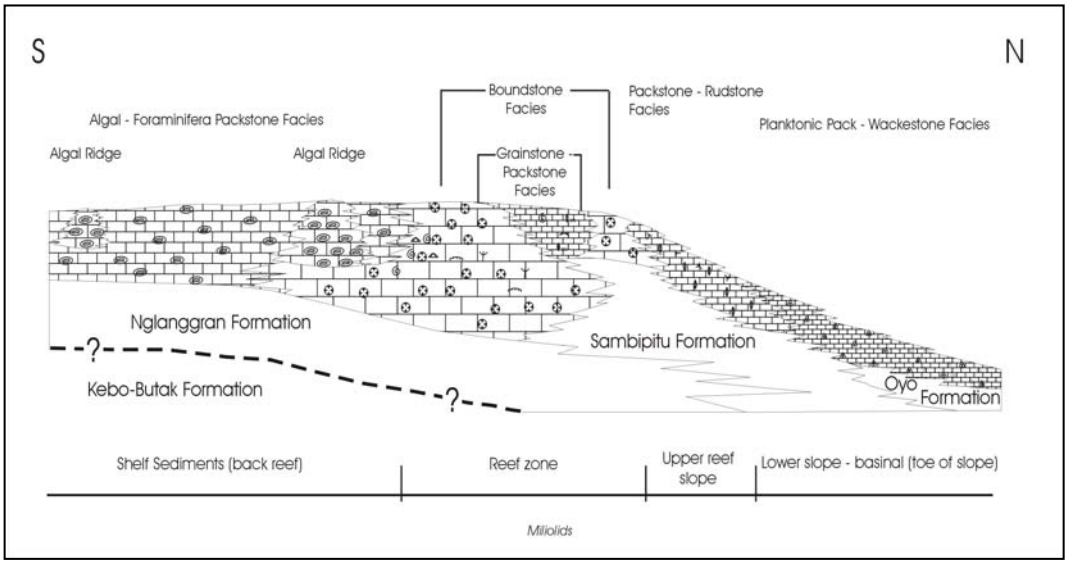


Figure 13. Hypothetical cross-section showing facies relationships of Wonosari Limestone.

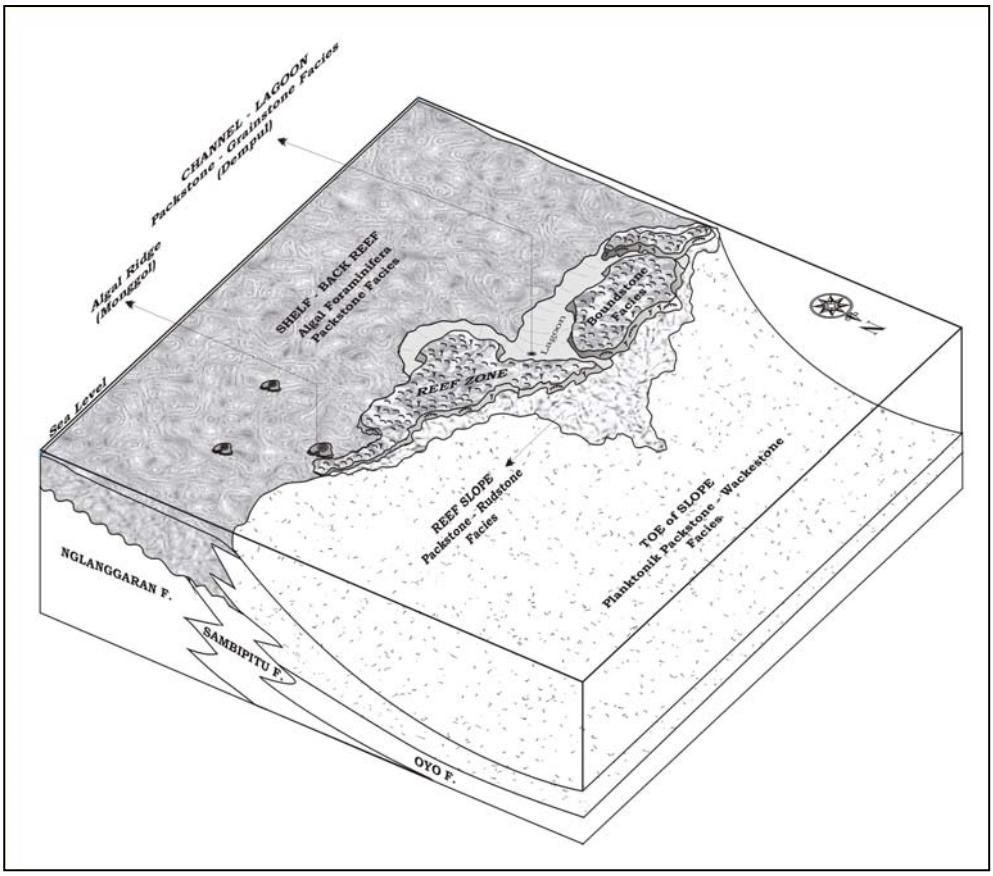


Figure 14. Hypothetical carbonate sedimentation model of Wonosari Limestone.

7. Algal-foraminiferal packstone facies, poorly and thick bedded, very poor sorted, abundant in algal (onkolites) and larger foraminifera. This facies represent back reef to shelf sedimentation.
8. The Wonosari Formation is interpreted as a rimmed shelf platform extending relatively in east-west direction with a basin to the north.

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