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Allostratigraphy of Punung Paleoreef based on Lithofacies Distributions, Jlubang Area, Pacitan Region-East Java

Allostratigrafi Paleoterumbu Punung berdasarkan Sebaran Litofacies, Daerah Jlubang, Kabupaten Pacitan, Jawa Timur

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ABSTRACT

Lithologically, Punung Formation as a paleoreef comprises coral boundstone rhodolith, algal grainstone, algal packstone, algal wackestone, algal floatstone, and algal rudstone. It is dominated by red algae and had formed a fringing reef in a warmly shallow marine environment. They built seven phases of paleoreef complex. Each paleoreef complex has been bounded by a local unconformity that is characterized by caliche. The Jaten Formation has becomes the base of the Punung paleoreef which build up by an angular unconformity contact on uppermost part. It consists of tuffaceous wacky sandstone with silicate cement. The formation as the reef base indicates two factors. The external factor because of the decrease of a volcanic activity and the internal one was caused by the depositional environment of the Jaten Formation becoming shallower. The subsurface runoff systems in many caves (like: Jaran cave and others) have the same southward direction to the dipping direction of algal grainstone lithofacies of Punung Formation. The vertical caves are formed by a jointing system.

Keywords: Punung Formation, paleoreef complex, allostratigraphy, caves

SARI

Formasi Punung disusun oleh litofasies boundstone koral, rhodolith, algal grainstone, algal packstone, algal wackestone, algal floatstone, dan algal rudstone. Batuan-batuan ini membentuk kompleks paleoterumbu, didominasi oleh algae merah berupa fringing reef di laut dangkal yang hangat. Paleoreef terbangun oleh tujuh fase dan dibatasi oleh ketidakselarasan lokal yang salah satunya dicirikan oleh keberadaan caliche. Formasi Jaten yang mendasari kompleks paleoterumbu Formasi Punung bagian atasnya yang memperlihatkan kontak ketidakselarasan menyudut tersusun oleh batupasir wake tufan dengan semen silikat. Terbentuknya Formasi Jaten sebagai dasar paleoterumbu dipengaruhi oleh dua faktor yaitu, eksternal, karena berkurangnya kegiatan vulkanisme, sedangkan faktor internal karena mendangkalnya lingkungan sedimentasi Formasi Jaten. Aliran sungai bawah tanah pada Goa Jaran dan beberapa "luweng" searah dengan kemiringan perlapisan litofasies grainstone algae Formasi Punung, yakni ke selatan. Adapun pembentukan goa dan luweng disebabkan oleh sistem perkekaran.

Kata kunci: *Formasi Punung, kompleks paleoterumbu, allostratigrafi, gua*

INTRODUCTION

East Java located at the southeast margin of Sundaland is a very active zone that receives sediments during Tertiary. Particularly in the Southern Mountains, an E-W old volcanic-arc had occured since Late Eocene. It is very widely distributed forming thick deposits. Nowadays, this area becomes a fore-arc zone. The changing phases have resulted in various sediments and depositional environments, ranging from siliciclastics deposited as shallow marine sediments and turbidites to paleoreef and bioclastic sedimentation in a shallow marine. This zone always becomes an interesting place for geological

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studies, particularly the karst topography in Punung Basin situated in the Southern Mountain (Gunung Sewu) that is proposed as the National Heritage of Indonesia.

The aims of the study are composed of five programmes. First is to explore more paleoreef stratigraphy of the Punung Formation. Currently, it is called as Allostratigraphy (North American Commission on Stratigraphic Code, 1983). The Allostratigraphic Unit is a mappable stratiform body of sedimentary rocks that is defined and identified on the basis of its bounding discontinuities. A formal allostratigraphic unit should be mappable at the scale practiced in the region where the unit is defined. It must indicate internal characteristic (physical, chemical, and paleontological) that may vary laterally and vertically throughout the unit, relation to a geomorphic surface, and relations to soil and paleosols. The Allostratigraphic Unit consists of Alloformation, Allomember, and Allogroup. Then, to get a better understanding for the contact between Jaten and Punung Formations and their depositional environments. Third to generate the Punung Formation that was formed by many phases of reef unit. Nowadays, the Southern Mountains reach thousands meters of elevation above sea level. Uplifting and sea level changes have influenced highly to the exposure of this area. Fourth is to restrict build up reef, because the environment has been changed during rise and fall of sea level. It means that the reef of Punung Formation has become the evidence of many local unconformities. Finally to know reef type and the initial reef forming and producing carbonate sedimentation of the lower Jaten Formation.

The assumptions are that restricted distribution in reef sedimentation depends on environment factors and as an unconventionally stratigraphic law it is valid for reef setting rule as well as Allostratigraphy. Furthermore, each reef setting has been bounded by an unconformity.

Methodology

Stratigraphically, younger sediments overlie older rocks. However, this insitu build-up reef and their sediments followed a conventional stratigraphic law as a Superposition law (Figure 1). An accumulative induction method is used to determine some criteria, such as lithofacies, stratigraphic positions, depositional environments, and age. To get a better interpretation of reef boundaries, both lithofacies and distribution of morphologic criteria were used as well as morphologic gap of ridge topography, and determined *caliche* distribution. Moreover, by a surface mapping, the location of lithofacies type and pipe solutions have been determinated within outcrop sampling. The hand-specimens samples are slabbed and prepared as thin sections. The three components above were overlied to overview the morphological features. The lithofacies was classified by a textural determination (Embry and Klovan, 1971). The flow chart of this study can be seen in Figure 2. The classification of reef complex type is used on the basis of Tucker and Wright (1990) while the diagenetic environment was used according to Choquette and Pray (1988) and Hanford and Loucks (1993).

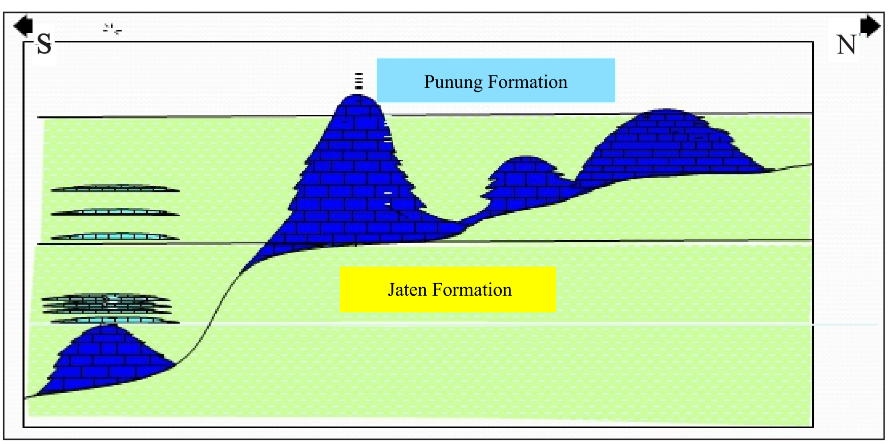

Figure 1. Paleoreef stratigraphy (Allostratigraphy) of Punung Formation overlying siliciclastics of Jaten Formation.

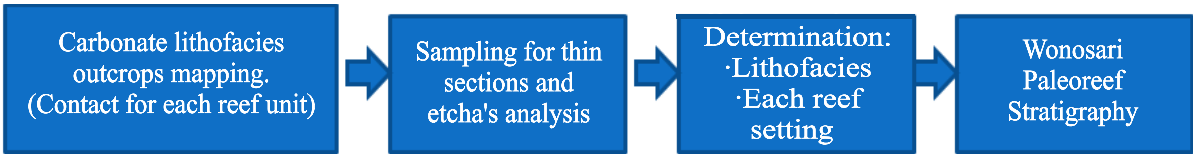

Figure 2. Flow chart for study of paleoreef stratigraphy of Punung/Wonosari Formation.

Regional Tectonic Framework

Hall (2002) concluded that East Java regions are occupied by important deposits of very thick siliciclastic and carbonate sediments, which could be of exploration interest as potential reservoirs in the back-arc basin since Paleogene. Recently, those sediments are accumulated along the volcanic arc in the central axis of Java. The fore-arc has been filled with old and largest volcanic sediments sourced from offshore regions. Many of the sequences previously were described as sedimentary volcanics or reworked volcanic rocks, where the volcanic material is present in almost every sequence of the basin. The volume of tuffaceous volcanic material within East Java sequences has previously been greatly underestimated. Grains in some of the quartz sands were clearly as volcanic origins.

Physiographically, East Java is divided into four zones based on the stratigraphy and structure which from south to north are Southern Mountains, present-day volcanic arc, Kendeng Zone, and Rembang Zone. Southern Mountain Zone contains the oldest surface exposures of sediments within East Java. The Southern Mountain during 35-20 Ma was as a volcanic arc that produced Old Andesite Formation (Van Bemmelen, 1949; Hall, 2002). Middle Eocene quartz-rich sands and conglomerates rest unconformably on a Cretaceous basement which can be examined at Karangsambung-Kebumen Region, Jiwo (near Klaten-central Java) and Nanggulan (20 km westward from Yogyakarta City). The Oligocene volcanism is dominantly represented by andesites and dacites as part of the Old Andesite Formation. The axis of the Oligocene arc can be mapped from exposures and approximately has a E-W direction. The axis of the Eocene arc does not exposed at the surface today but it is assumed to follow the same orientation as the Oligocene arc. Among volcanic centres, pyroclastic deposits are reworked, including sheet sands and turbidites.

An extensive exposure of the active volcanic centre was present during Oligocene. The arc is obviously located on Southern Mountains from Middle Eocene to Middle Miocene. The flanks of the volcanoes occur as a landform with river systems feeding into a shallow marine setting to the north (such as the Kebobutak Formation at Jiwo Area, Klaten). Paleoreefs locally developed (Campurdarat Formation near Tulungagung, East Java) between the volcanic centres or within calderas that provided shallow water environments (Smyth *et al.*, 2003). The Southern Mountains during 20 - 5 Ma was a fore-arc basin that produced the thick Punung paleoreef restricted until 15 Ma (Van Bemmelen, 1949; Hall, 2002).

Analysis Result

Jlubang area is located in Pacitan Regency of East Java Province (Figure 3). Morphologically, as part of cone hills and karst topography, the studied area has either dipping or sloping southward (onshore bordered to Indonesian Ocean). Many caves are present, for example: Gua Jaran (the longest vertical cave in this area) besides luweng (small caves), voclus, and dolines in other areas.

Geologically, the quartz sandstone of Jaten Formation (yellow colour) crops out in the middle of the studied area spottedly and oriented to the northeast. Determination on planktonic foraminifera contained within claystone intercalation resulted in Middle Miocene age (N9 - N15 of Blow Zonation, *in* Blow, 1969). As the base of initial paleoreef of Punung Formation (Figure 4), the Jaten lithofacies exist as wacky quartz sandstone (Figure 5).

Lithofacies of Punung Formation

The Jaten Formation sandstone consists of coarse-to very fine-grained sand and silicate cement.

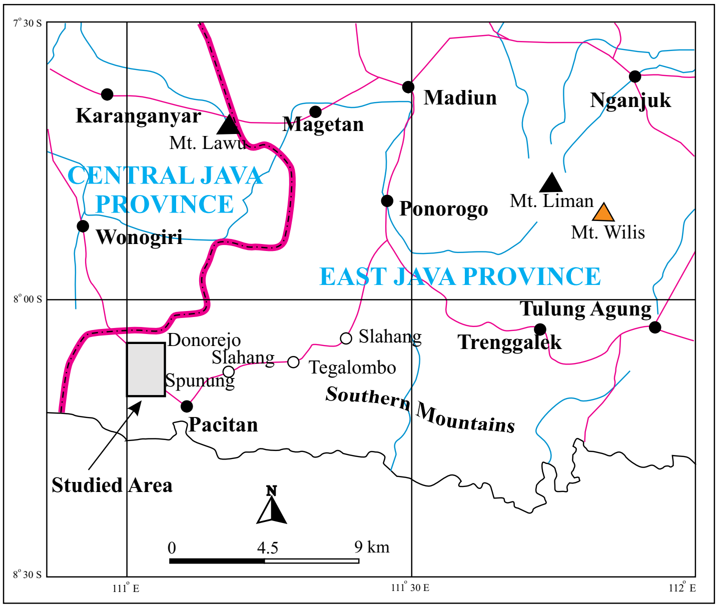

Figure 3. The studied area is located in Jlubang area and it belongs to the Southerns Mountain.

Petrographically, sample from the uppermost of Jaten Formation comprises quartz fragment and microcrystaline of almost 20%, mud 80%, and opaque mineral 1%. The lithologic name of wacky quartz sandstone indicates mud dominated (Figure 5). Age of the sample is Middle Miocene or N9 - N15 (Blow Zonation, *in* Blow, 1969).

The Punung Formation is made up of reef either massive or bedded lapies (robust and rough hole on surface), vuggy, moldic, and cave porosity. The dipping is almost similar to the Jaten's, occuring as the basement of reefs. Etcha slabbed and thin section analyses, show that the lithofacies consist of coral boundstone, rhodolith (red algal boundstone), algal grainstone, algal packstone, algal wackestone, algal floatstone, and algal rudstone (Figure 6) and many lithofacies sections of reef stratigraphic unit. Alternation between a dipping of Punung Formation in this area and slope of basement are about 15° - 20° where the reef forming fringing reef (Figure 7).

The Jaran Caves, the longest vertical caves in Punung area have been mapped and studied by Australian-Indonesian Speleologists. They reported that the subsurface runoff system in the cave has the same direction to the dipping direction. The lithofacies of the cave mouths are composed of algal grainstone lithofacies. The vertical caves are formed by a jointing system (B6-Figure 6).

Discussion

The formation of reef unit is influenced by local sea level changes (Premonowati, 2005). The local controls on the growth of the reef unit took place within the context of global changes.

Five important points relating to the context of global changes are described as follows:

1. In environments where carbonate is available like red algae growing during sea level rise, keeps pace with these surrounding basal clastic sediments of Oyo Formation. Next step, it is common to find thick, high relief, and often backstepping carbonate successions in Wonosari Formation. It was regionally formed during Oligo-Miocene (Sarg *et al*., 1999; Miller *et al*., 2005).
2. The fluctuations were often as high as ±100 m, which resulted in frequent and common long-term subaerial exposure of reef and bioclastic carbonate sediments. This emergence led to the establishment of freshwater lenses which initiated meteoric diagenetic processes resulted in the development of karst terrains including cave systems, like hundred of caves in Southern Mountains.
3. Concurrently, the initiation of the major cooling event in the Tertiary and a shift in the ocean chemistry occurred. These activity favoured aragonite and high-magnesium calcite (HMC) to

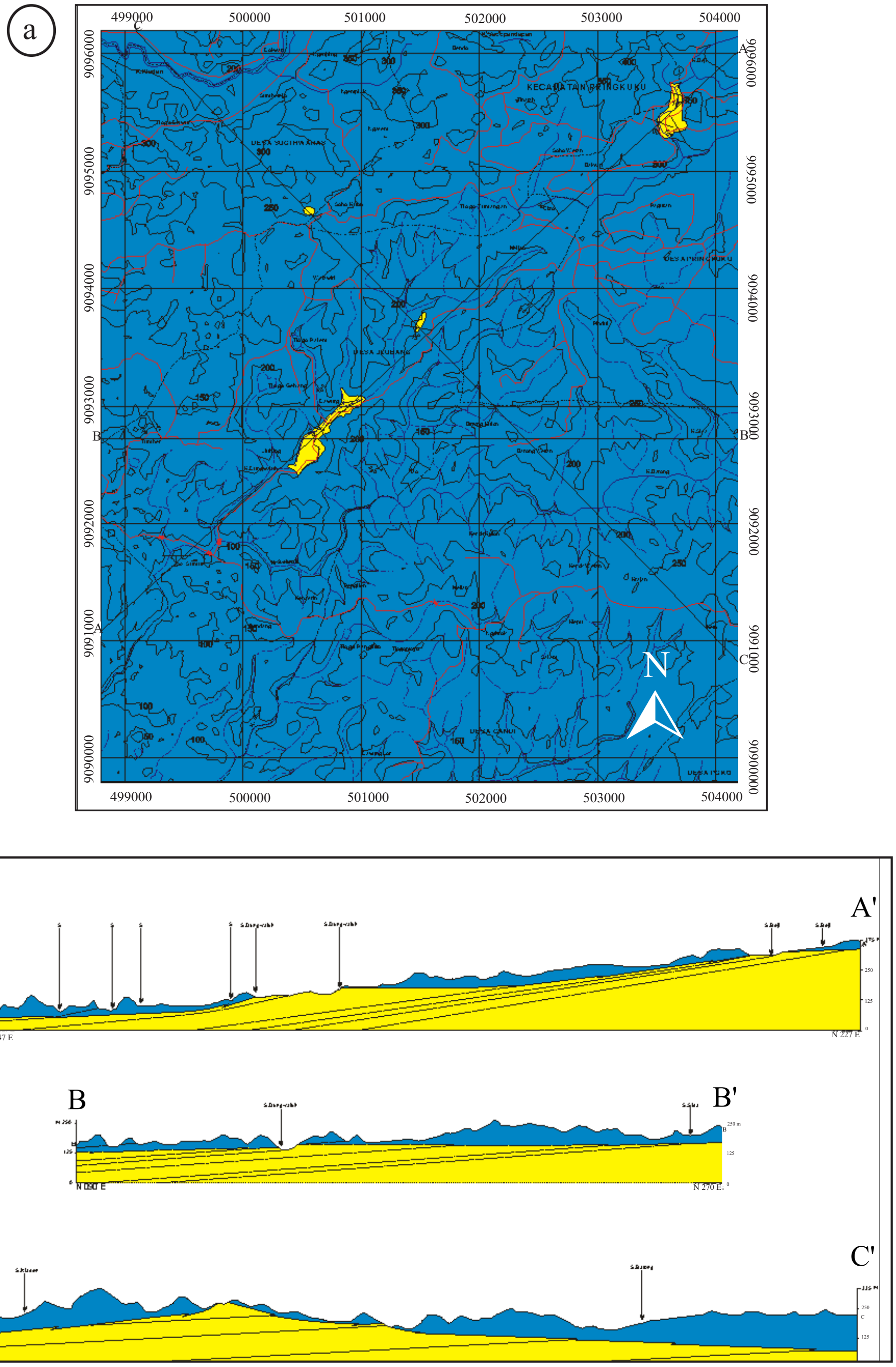

Figure 4. a) Geologic map of Jlubang area. The Jaten Formation (Yellow color) distributed spottly and NE orientations. Almost 90% outcropped of paleoreef Punung Formation (Blue color). Black crosslines is direct of sections (see below), b) The geologic sections of Jaten and Punung Formation conical hills and karst topography, gentle dipping to the south.

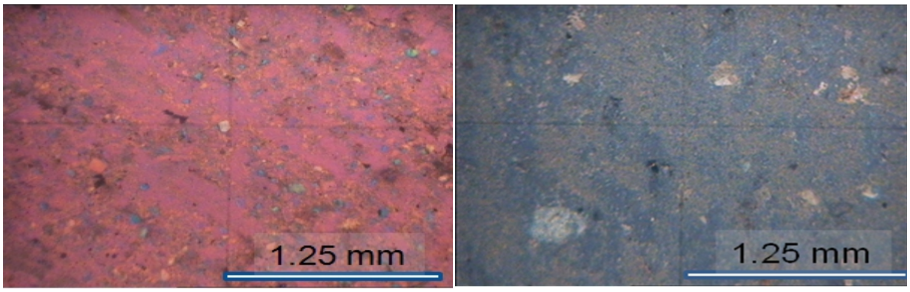

Figure 5. Thin sections of wacky quartz sandstone of Jaten Formation showing muddy dominantly. Right: crossnicol; Left: parallel nicol.

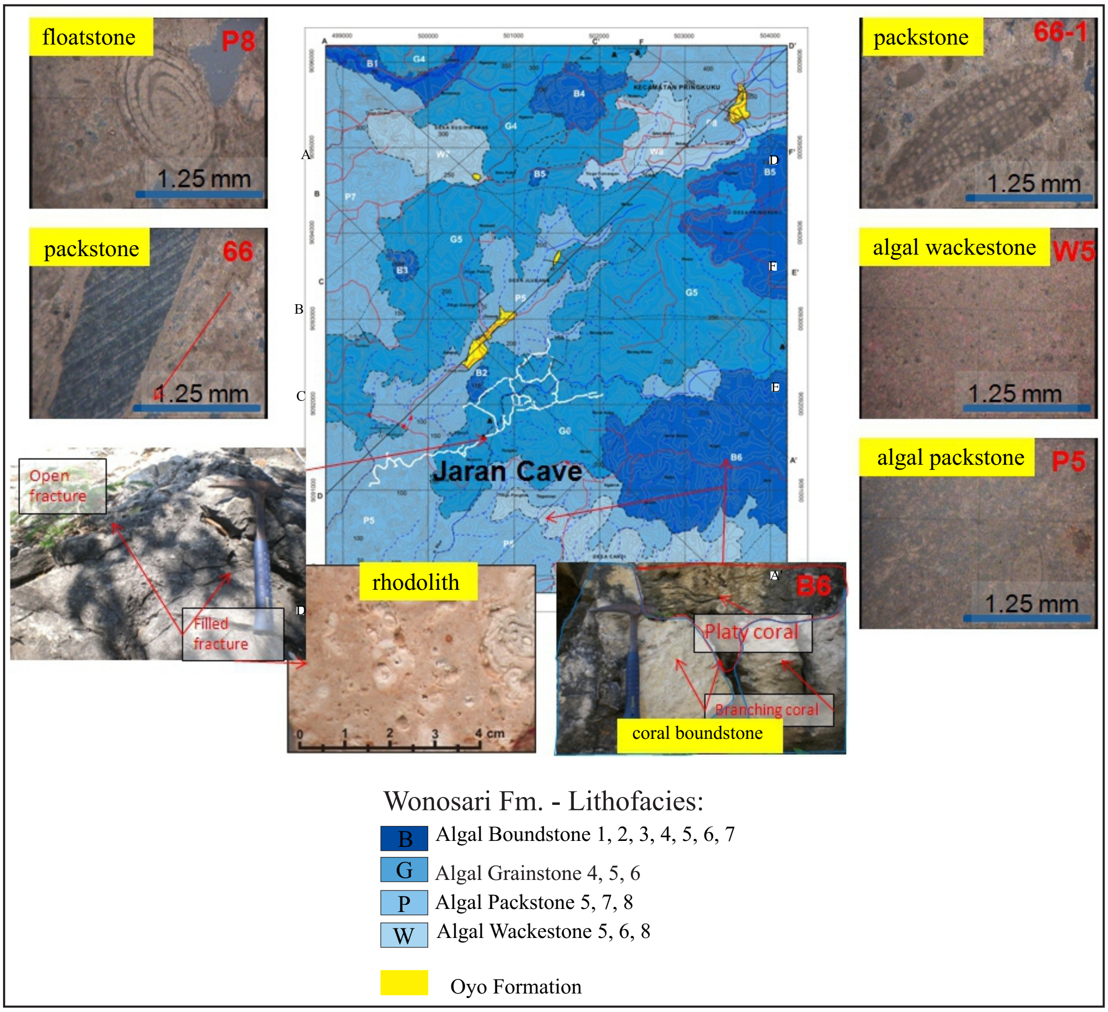

Figure 6. Lithofacies map of Punung Formation (gradual blue color) (Top centre) and the lithofacies (Diagram of Lithofacies Strata). It indicates one of reef units covered to each other. Symbols of B1 (Boundstone-1/dark blue) overlies G4 (Grainstone-4/lighter) (see NW corner), and so on until P8 (Packstone-7/light blue) (see near NE corner).

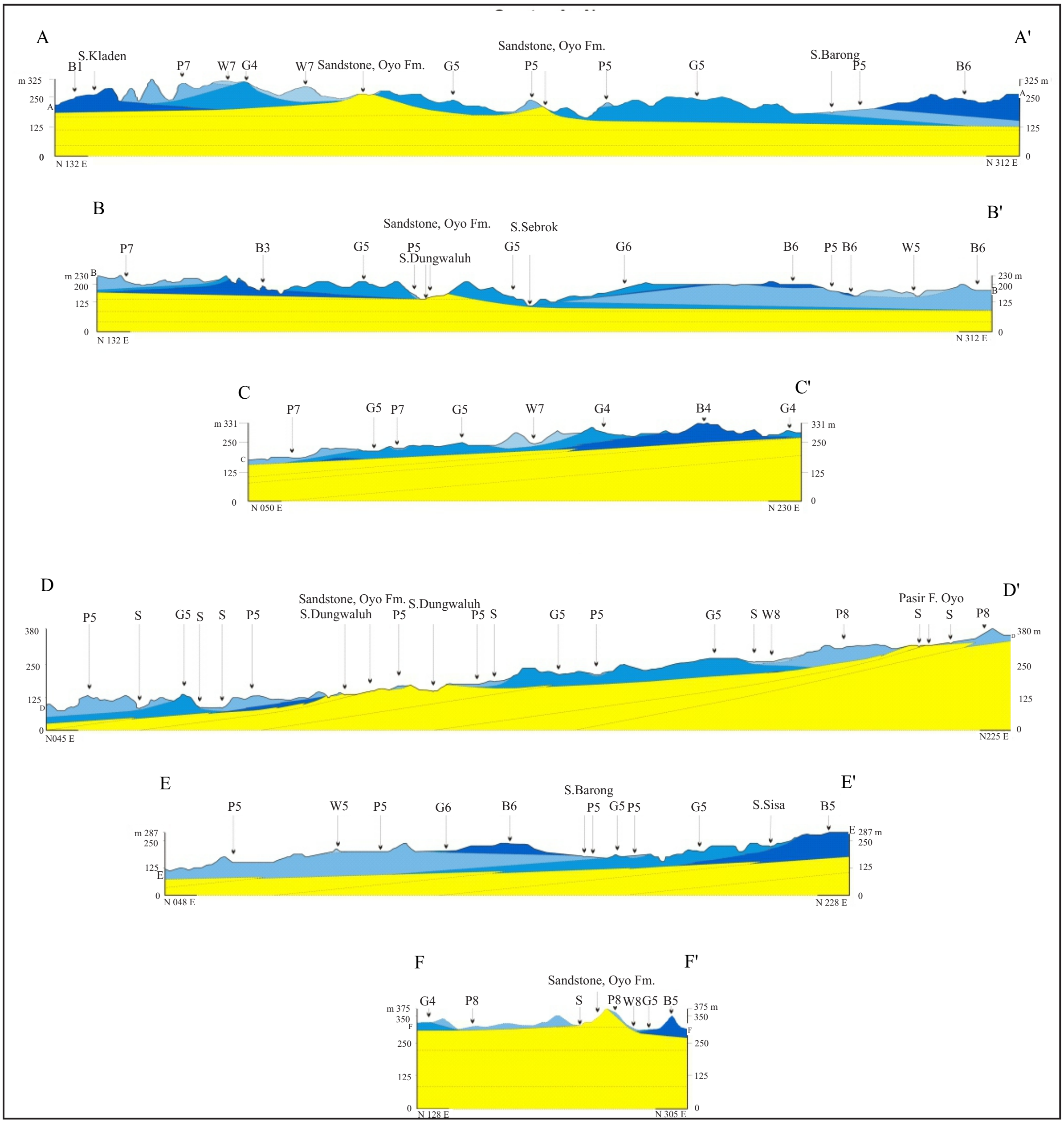

Figure 7. The lithofacies sections of Punung Fm. shows an almost similar gentle dipping to Jaten Formation (the paleoreef base) and one reef unit overlaid to each other. It indicates the fringing reef (based on geological map in Figure 6/Jaran Cave).

dominated coral-algal reef communities. Both are more susceptible than low magnesium calcite to dissolution and recrystallization when exposed to meteoric waters. Meteoric diagenesis has a great effect on the secondary porosity and permeability systems in these sediments.

4. During the Early Miocene, reef development increased worldwide and scleractinian corals emerged as a dominant frame-building component (Hanford *et al*., 1984). These corals can grow at high rates, approximately 1 cm per year on the average and up to about 20 cm per year in modern studies of branching forms (Edinger *et al*., 2000). As part of a constructional framework of other corals and encrusters such as red algae, scleractinians increase the capability of carbonate buildups to keep pace with all but the most rapid increases of relative sea level. This provided the robust framework construction for the high-relief carbonate edifices imaged in seismic and found in many tropical and subtropical regions today.
5. Particularly, caliche in the Punung Formation is paleosoil limestone forming all carbonate facies. Caliche is a massive/unstratified, fine to coarse grained, fragile, and structure framework or biota with high porosity as moldic porosity and white powder still remains. The caliche formation crops out as a fringing reef locally, similar to the Punung distribution as fringing algal-coral reefs. Moldic porosity indicates a diagenetic environment of supratidal/terrestrial. This is the product of secondary terrestrial carbonate with high saturation and damp. It has been proven that there are solution process and paedogenesis (soil forming). It is the coexistence to the karst topography.

Environment Interpretation

The caves with less cement indicate that caliche was produced during a diagenetic environment changes from saturation zone to vadose, to a phreatic zone until they are exposed to the surface. The caliche is massive or unstratified showing rate of whether spontaneously and changes to highly damp multiplication. It forms a karst topography.

The exposure of reef/limestone indications are as follows: 1. Pipe solutions; 2. Caliche (Figure 8); 3. Vuggy and moldic porosity, vein filled with opaque minerals/pyrites, and 4. contact massive head coral/algal boundstone and other lithofacies.

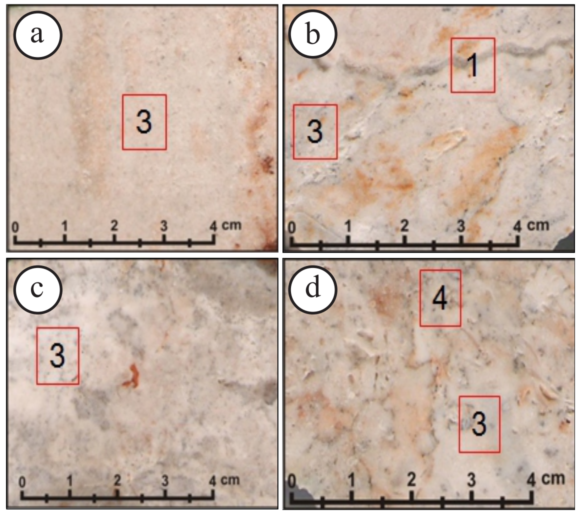

Figure 8. The etcha slabbed of Punung Formation signed point of reef exposure indications. a to d samples almost all caliche. The contact (no.4) has been shown in the previous lithofacies sections.

The caliches and pipe solution indicate a strongly wheatering process that occured within limestone. They are co-existent with karst topography in humid areas.

Conclusions

Punung Formation as a paleoreef is composed of coral boundstone, rhodolith (red algal boundstone), algal grainstone, algal packstone, algalwackestone, algal floatstone, and algal rudstone, dominated by red algal and forming a fringing reef in a warmly shallow marine. They have formed seven units of paleoreef complex, and overlay one to each other. Each paleoreef complex is bounded by the local unconformity characterized by the presence of pipes/solutions, vuggy and moldic porosity, caliche, and nearby contact lithofacies. The contact of Jaten, as a reef base, and Punung Formation is a gentle angular unconformity. The subsurface runoff systems in many caves (like: Jaran cave and others) have the same dipping direction with algal grainstone lithofacies of the Punung Formation. The vertical caves were formed by a jointing system. Punung Caliche is the product of secondary terrestrial carbonate with high saturation and damp. It is the coexistence to karst topography. The sea level changes and tectonic factors induced the form of paleomorphological features of basement for the reef growth of Punung Formation. The model of Punung paleoreef units is a patch reef.

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