Microfacies and paleodepositional setting interpretation of the latest Oligocene to earliest Miocene Carbonate of Citarate Fm., Bayah High, West Java

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ABSTRACT

Four hundred and ten samples were collected from carbonate outcrops of Citarate Formation in the Bayah High area, west of Pelabuhan Ratu, West Java. Petrographic analysis reveals 14 carbonate microfacies distributed in the study area, which include: (1) *Globigerinid* wackestone-packstone, (2) Foraminiferal bioclastic packstone-grainstone, (3) Foraminiferal algal packstone-grainstone, (4) Benthic foraminifera-rich grainstone, (5) Red algal foraminifera packstone, (6) *Globigerinid* bioclastic packstone, (7) Coralline algal packstone-boundstone, (8) Branching coral packstone-grainstone, (9) Foraminifera coralgal packstone-grainstone, (10) Platy coral foraminiferal algal packstone-grainstone, (11) Intraclast/plagioclase-rich packstone-grainstone, (12) Massive coral boundstone-rudstone, (13) Platy coral bioclastic packstone-grainstone, and (14) Platy coral boundstone grainstone.

Micropaleontological analysis of the carbonate microfacies reveals age distribution ranging from P22, N4, to younger than N4 (Blow's Zonation), and Te4 (Adam's letter stage), which are equivalent with the latest Oligocene to very Early Miocene Epoch.

Detailed stratigraphic observation from outcrops and micropaleontological analysis show a north-south carbonate trend. This trend happened to superimpose the structural lineaments of Bayah High. It is interpreted that a shallow depositional environment developed in the western part and became deeper towards the east.

This paper is part of a study of Oligo-Miocene carbonates and their relationship to tectonic events in West Java. By knowing the evolution of Oligo-Miocene carbonate rocks and their relationship with the tectonic development of West Java, it is possible to interpret the presence of these carbonate rocks below the surface for hydrocarbon exploration purposes.

Keywords: Citarate Formation, Oligo-Miocene Carbonate, Bayah, West Java

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INTRODUCTION

Tectonic setting is one of the genetic factors that influence the development of carbonate depositional system (Bosence, 2005; Playton et al., 2010; Pomar, 2001; Tucker & Wright, 1990; Wright, 1996; Zahirovic et al., 2022). During the Cenozoic, Southeast Asia encountered tectonic occurrence, and was influenced by tropical climate, relative sea-level changes, oceanographic properties, hydrodynamics that affected the distribution of carbonate deposits (Wilson, 2008, 2012; Wilson et al., 2010). However, the depositional system of the Cenozoic Carbonate in Southeast Asia in tectonic margin is still underexplored. Therefore, this study is carried out to investigate the Oligo-Miocene carbonates in the Bayah and Sukabumi outcrops, as well as Rangkasbitung subsurface of the Southeast Asian tectonic margin. By knowing the evolution of Oligo-Miocene carbonate rocks and their relationship with the tectonic development of West Java (the Southeast Asian tectonic margin), it is possible to interpret the presence of these carbonate rocks below the surface for hydrocarbon exploration purposes.

The study was carried out at Bayah High and its adjacent areas, about 25 km west of Pelabuhan Ratu (Figure 1). More than 15 traverses were completed along Cidikit, Cisawarna, Citarate Rivers and their tributaries, and covering Pamubulan, Lebak Tipar, Sawarna Villages (Figure 2). The carbonate is part of Citarate Formation. Sampling has been carried out from outcrops along the rivers and road cuts. The limestone outcrops of the Citarate Formation are located around the Bayah High area, overlying Cijengkol Formation, and the Eocene sandstone of Bayah Formation, which is exposed in the center of the study area.

Field mapping showed that Limestone only cropped out in a few places. Lack of continuity is possibly due to thick soil and vegetation. In some parts of the studied areas, limestone outcrops occurred in very steep and deep valleys, which makes assessing the outcrop locations challenging.

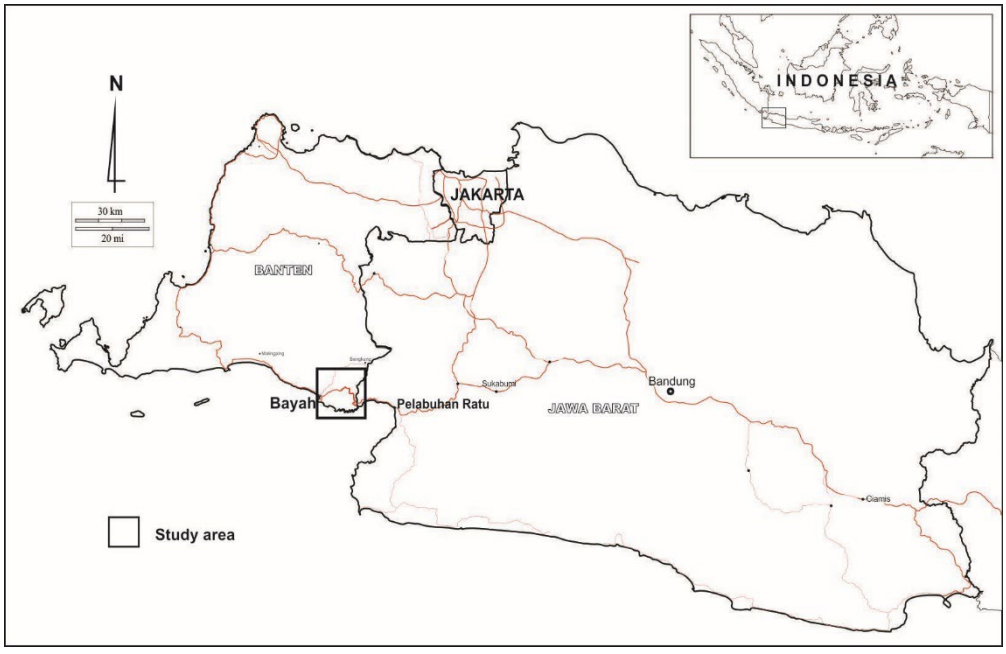


Figure 1: *Location map of the study area in Bayah, West Java.*

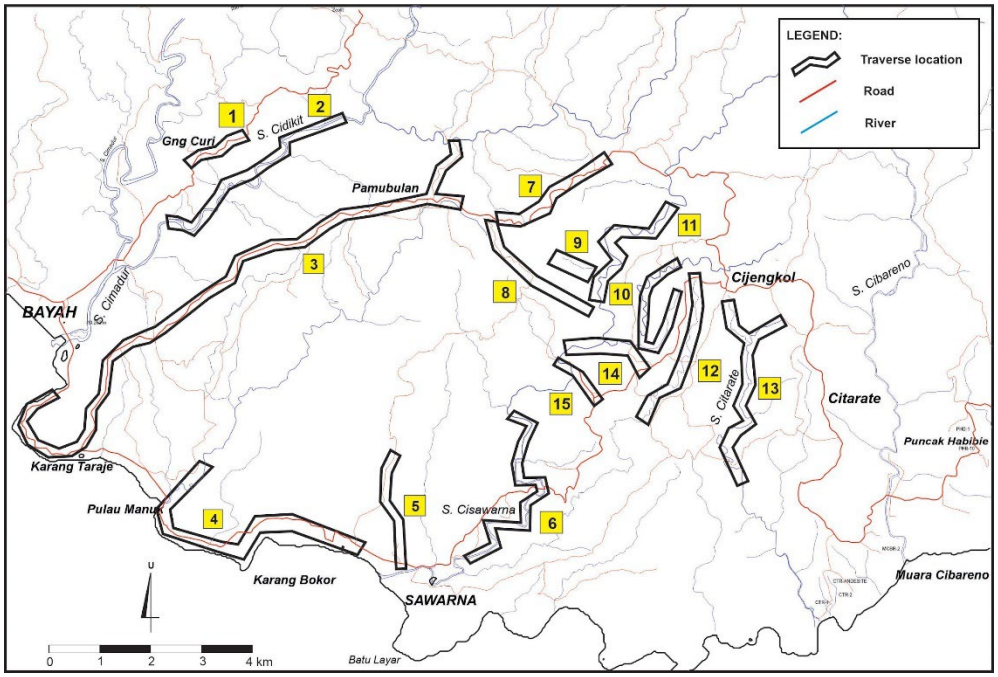


Figure 2: *The road and river map of Bayah showing traverses conducted in this study.*

GEOLOGICAL SETTING

Bayah Area is well-known for its numerous outcrops of Eocene fluvio-deltaic origin and the younger Oligo-Miocene shallow marine sediments. Bayah stratigraphy was studied by Koolhoven (1933), Baumann (1973), Martodjojo (1984), Sujatmiko and Santosa (1992), and was revisited by Lunt (2013). The stratigraphy is summarized in a stratigraphic column as shown on Figure 3, which consist of the following formations (in old to young order):

Bayah Formation (Eocene): This formation is predominantly composed of fluvio-deltaic quartz sandstones and conglomerates, with minor black shales, seams of allochthonous coal and tuff beds. The thickness of the formation is 1500 m or even more. According to Koolhoven (1933), there are more marine facies occurring to the north, with clays, marls, quartz sandstones and foraminiferal limestones.

Cicarucup Formation (Late Eocene): Andesitic conglomerates and sandstones, quartz sandstones, marls, clays, and foraminiferal limestones with *Discocycline, Pellatispira* and *Nummulites djogdjakartae*.

Cijengkol Formation (Oligocene): Several authors (Koolhoven 1933, Baumann 1973) suggested that this formation unconformably overlies the previous formation. The lower part of Cijengkol Fm. consists of conglomerates, tuffs, breccias, and coal lenses, that grade upward into sandy marls with foraminifera, reef- and marly-limestones and marls. The thickness of the formation is several hundreds of meters or more. Larger foraminifera was reported and the suggested age is Oligocene.

Citarate Formation (Latest Oligocene): This formation includes reefal limestones at the base, locally with terrigenous detritus (300 - 500 m), overlain by up to 1000 m of light green calcareous sandstones, interbedded with sandy limestones, marls, andesitic tuffs, and conglomerates. The larger foraminifera assemblage suggests the Lower Te zone (Late Oligocene, Adam's - 1984 Letter Classification).

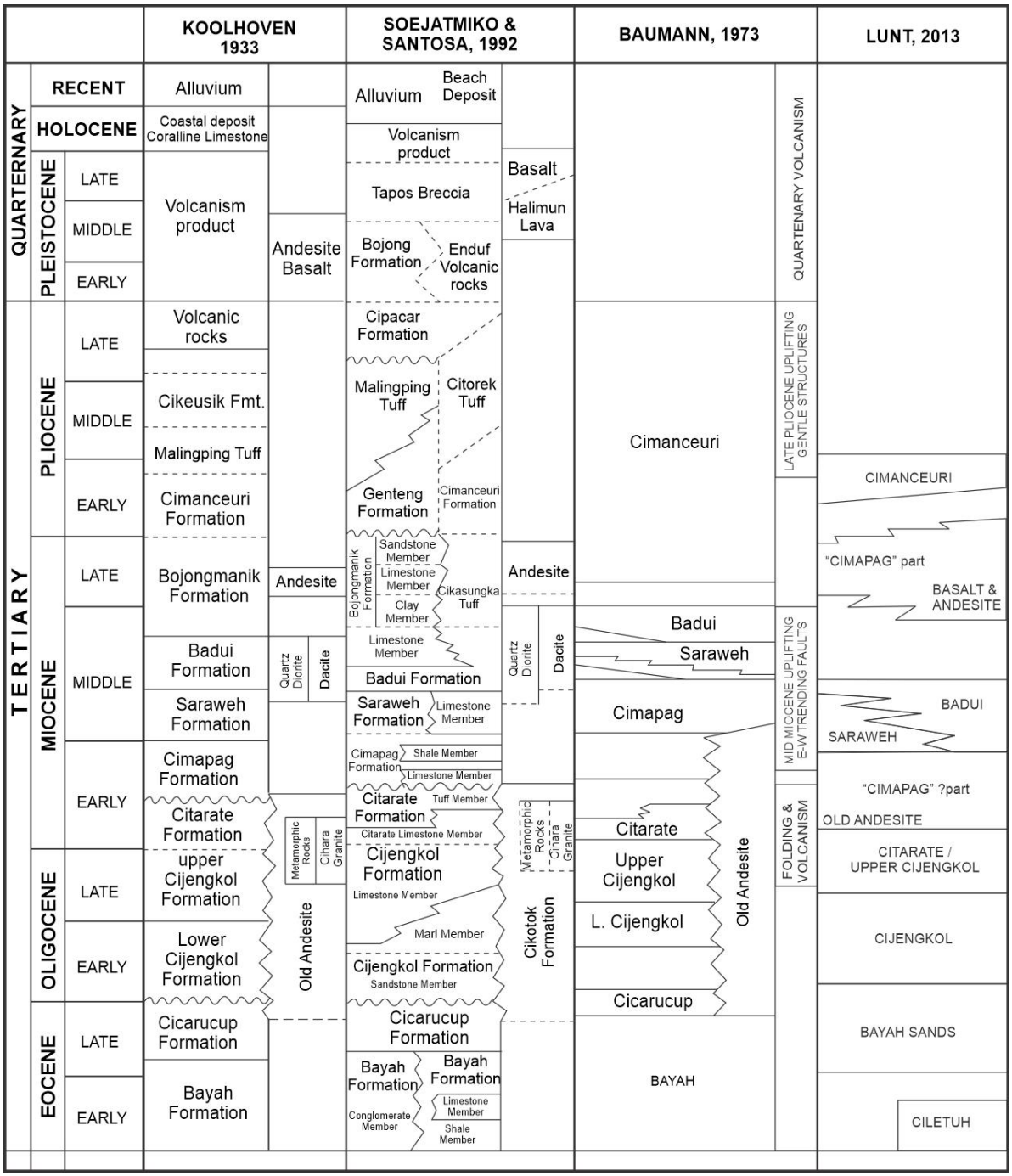


Figure 3: *A compilation of Bayah stratigraphic column from various authors.*

Cimapag Formation (Early Miocene): This formation unconformably overlies the older formations. It is directly overlying the Eocene Bayah beds and in other areas, overlies either Old Andesites, Cijengkol, or the Citarate beds. The estimated thickness of the formation is 900 m. The basal beds are polymictic conglomerates, composed mainly of andesitic volcanic material, but also with clasts of older sediments and even metamorphic basement rocks such as muscovite schist, gneiss and phyllite. These beds grade upwards into a variable series of poorly bedded volcanoclastics (andesitic and dacitic tuffs), interbedded with reef limestones and marine sandstones and clays. The presence of *Spiroclypeus, Eulepidina* and *Miogypsina dehaarti* suggests the age of Upper Te zone (Early Miocene).

Quaternary Volcanic: This unit differs from the Pliocene volcanic by the occurrence of andesitic-basaltic rocks, rather than dacitic composition. This unit unconformably overlies the folded Pliocene and older rocks.

Structurally, the area is very complex, with numerous faults, folds, and igneous intrusions. Geological map by Koolhoven, 1933 (Figure 4) show an E-W trending anticlinal and synclinal structures (north-directed thrusting according to Koolhoven, 1933) and numerous faults trending north or north-northeast.

the same direction trends in the north of offshore Java, around the Seribu Islands.

Sribudiyani et al. (2003) published a structural map of West Java based on the surface and subsurface data as shown in Figure 5. The map shows N-S to NNE-SSW major structure lineaments in West Java, both on surface and in the subsurface.

Diagenetic study of some parts of the Citarate Formation carbonate microfacies was previously done by Basuki and Wiyoga (2012). They suggested nine phases of

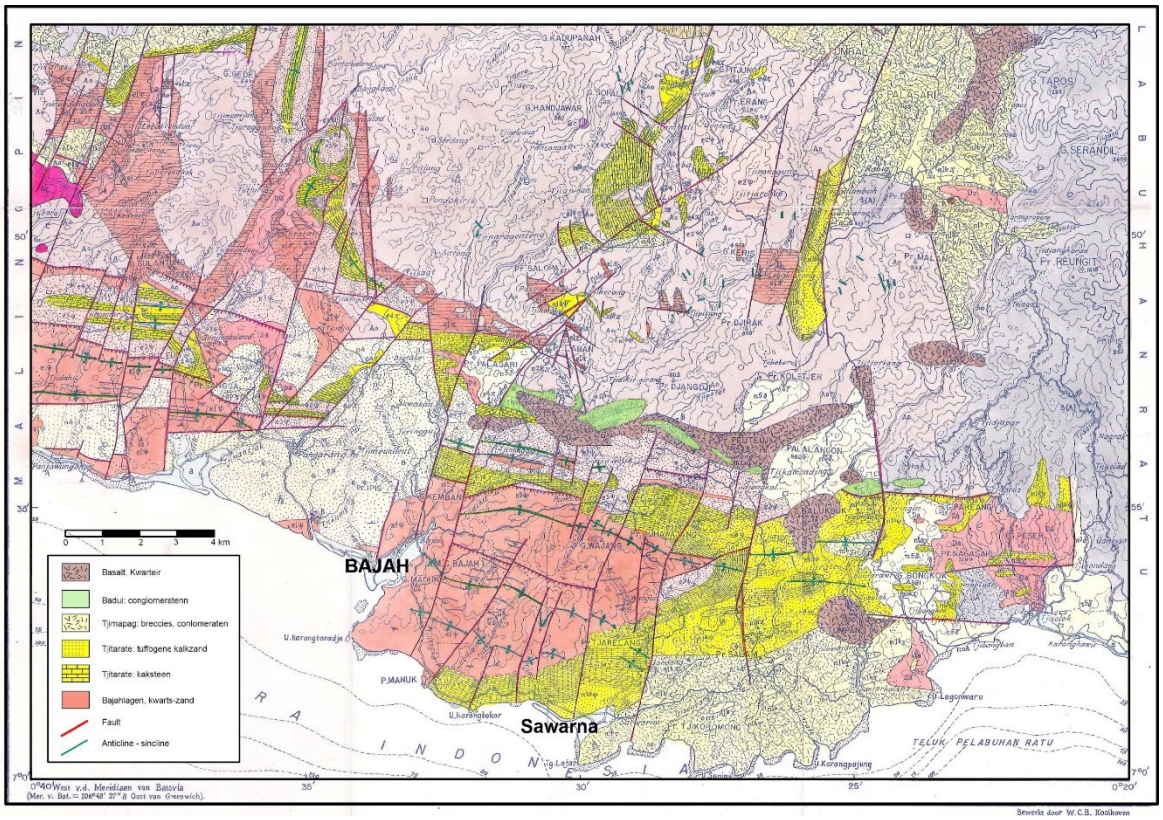


Figure 4: *The geological map of Bayah showing N-S faults (Koolhoven, 1933).*

Baumann et. al (1973) inferred four tectonic phases in the SW Java, which consist of: (1) Late Oligocene - earliest Miocene folding, associated with volcanism in the Bayah High ("Old Andesites"); (2) A major event in the Middle Miocene, causing uplift, E-W trending folds and intensive faulting; (3) A Late Pliocene phase of uplift and gentle folding; and (4) Quaternary volcanism.

Martodjojo (1984) correlated the N-S structural trends in the Bayah High with

diagenesis, from near surface to shallow depth (phases I-III), phases IV to VI occurs during deeper to maximum burial diagenesis, and phase VII to XI represent time between maximum burial and subaerial exposure at present condition.

METHODS

In this study, rock samples were gathered from 15 traverses, with a detailed

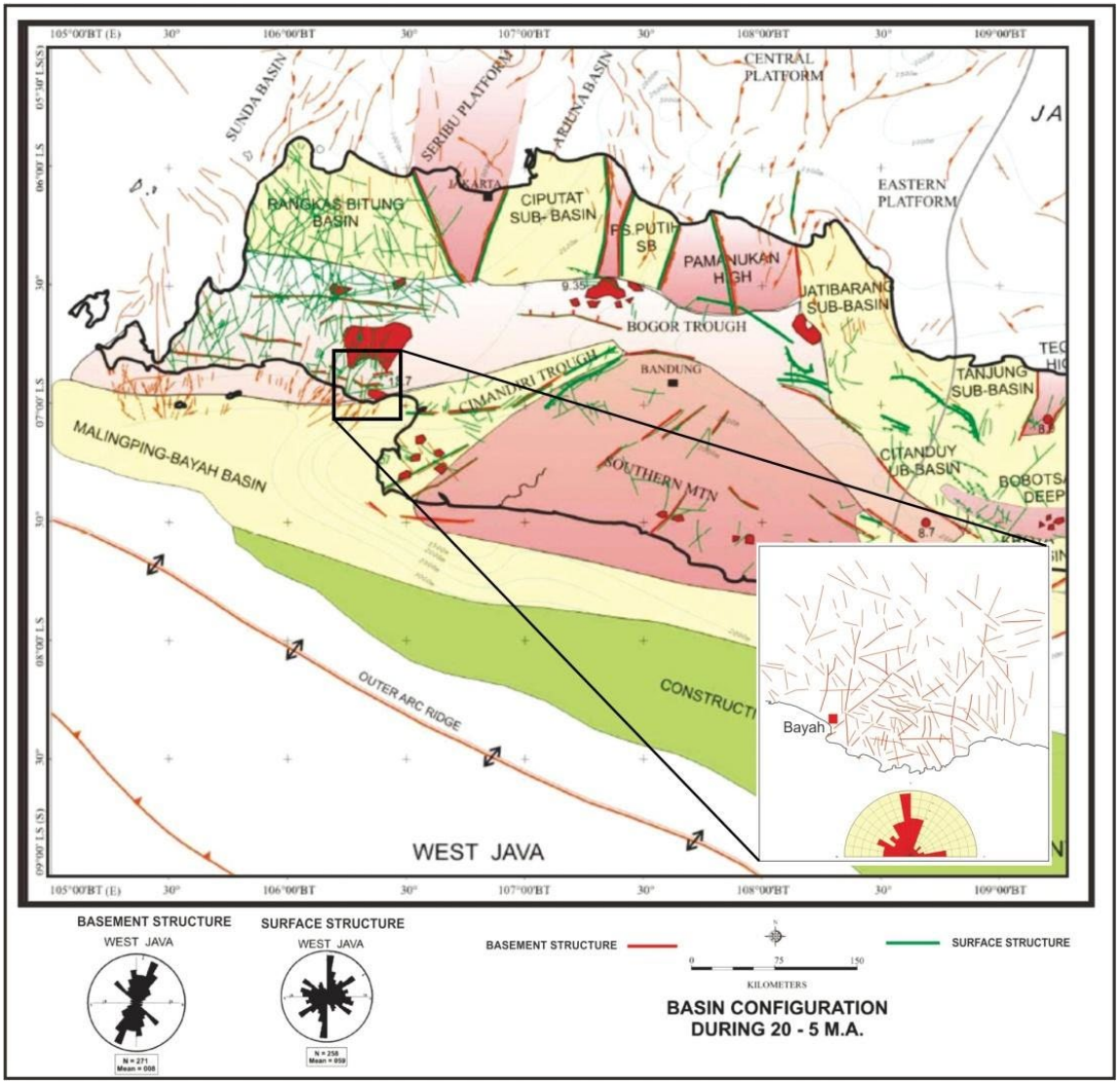


Figure 5: *The structural trends in West Java during Miocene (Sribudiyani et al., 2003). Inset: structural lineament in Bayah area based on Digital Elevation Model (DEM) data. DEM source: https://earthexplorer.usgs.gov.*

stratigraphic measuring section reconstruction for each traverse. A total of 410 samples were collected, 247 of them were slabbed to produce thin sections (Figure 6). The thin sections were prepared using a large preparation glass (1" x 2") to obtain a better depositional texture interpretation. The type and abundance of grain, matrix, cement, and porosity components have been estimated using the point counting method. More than 20 rock components were identified. Carbonate classification was using Dunham (1962) classification. Almost 250 samples were analyzed and cluster analysis was performed to construct rock-type grouping.

Seventy-two samples were analyzed for quantitative micropaleontology. Both residue and thin section analyses were performed. Planktonic zonation referred to Blow zonation (1979), while larger foraminifera zonation was referring to Adam (1984). The result determined the age and the depositional environment of the samples.

The depositional environment was established by integrating the slab, petrographic, micropaleontologic, and

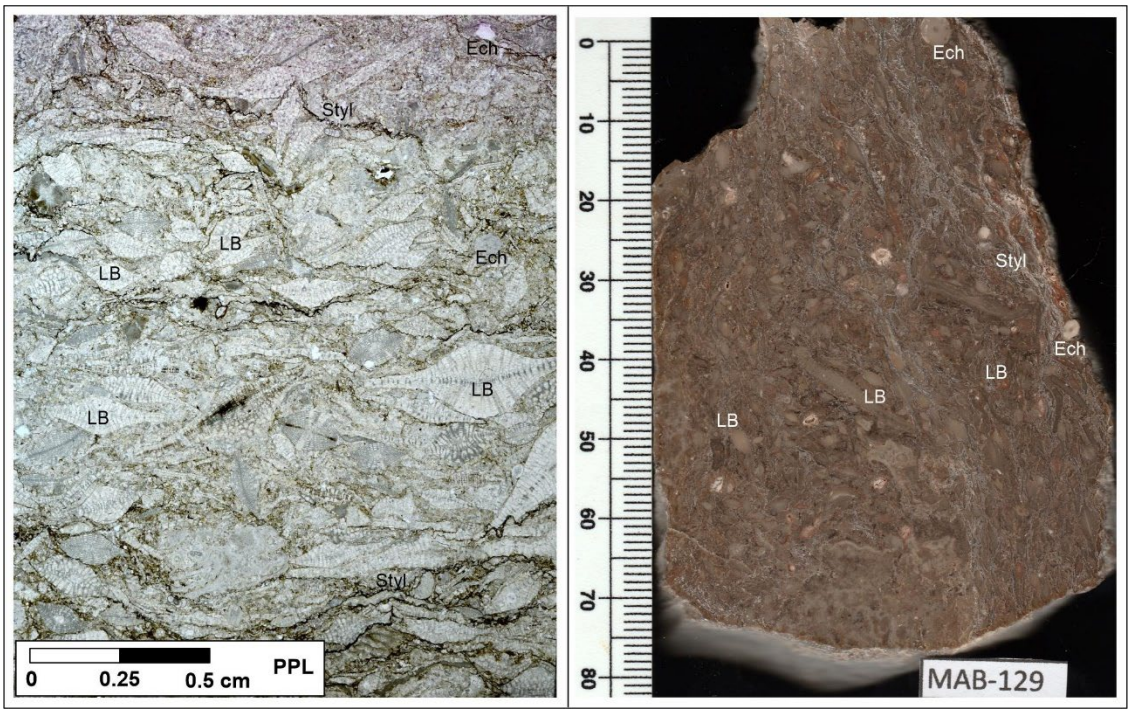


Figure 6: *An example of thin section photomicrograph (left) and the slabbed sample (right) from location MAB-129 (location: Ciawi, traverse no 11, Figure 2). The rock contains predominantly large foraminifera (LB) and echinoid spines (ECh), low amplitude stylolite is observed. This rock is classified as Benthic Foraminifera-rich Grainstone.*

sedimentological data. The depositional environment was then plotted onto Wilson's (1975) Standard Microfacies (SMF) system to obtain a suitable carbonate depositional model for the study area. From the interpreted depositional environment, local relative sea level rise and fall were analyzed and then plotted for each traverse. Figure 7 exhibits one of the stratigraphic columns from Pamubulan – Cijengkol traverse.

Stratigraphic cross-section and fence diagrams were also reconstructed across the entire study area.

CARBONATE MICROFACIES, DEPOSITIONAL ENVIRONMENT AND AGES

Based on 247 slab and thin section samples and 163 hand specimens, we recognized 14 carbonate microfacies (Figure 8), which are: (1) *Globigerinid* wackestone-packstone, (2) Foraminiferal bioclastic packstone-grainstone, (3) Foraminiferal algal packstone-grainstone, (4) Benthic foraminifera-rich grainstone, (5) Red algal foraminifera packstone-grainstone, (6) *Globigerinid* bioclastic packstone, (7) Coralline algal packstone-boundstone, (8) Branching coral packstone-grainstone, (9) Foraminifera coralgal packstone-grainstone, (10) Platy coral foraminiferal algal packstone-grainstone, (11) Intraclast/plagioclase-rich packstone-grainstone, (12) Massive coral boundstone-rudstone, (13) Platy coral bioclastic packstone-grainstone, (14) Platy coral boundstone-grainstone.

The distribution of the mentioned carbonate facies is shown on Figure 9. The abundance of dolomite and milliolids are also plotted on the map as depositional environment indicators. Microfacies 3 (Foraminiferal algal packstone – grainstone) and microfacies 9 (Foraminifera coralgal packstone grainstone) are commonly found in Gunung Curi and Cidikit River. If massive coral and larger foraminifera are present, they are partially bounded by red

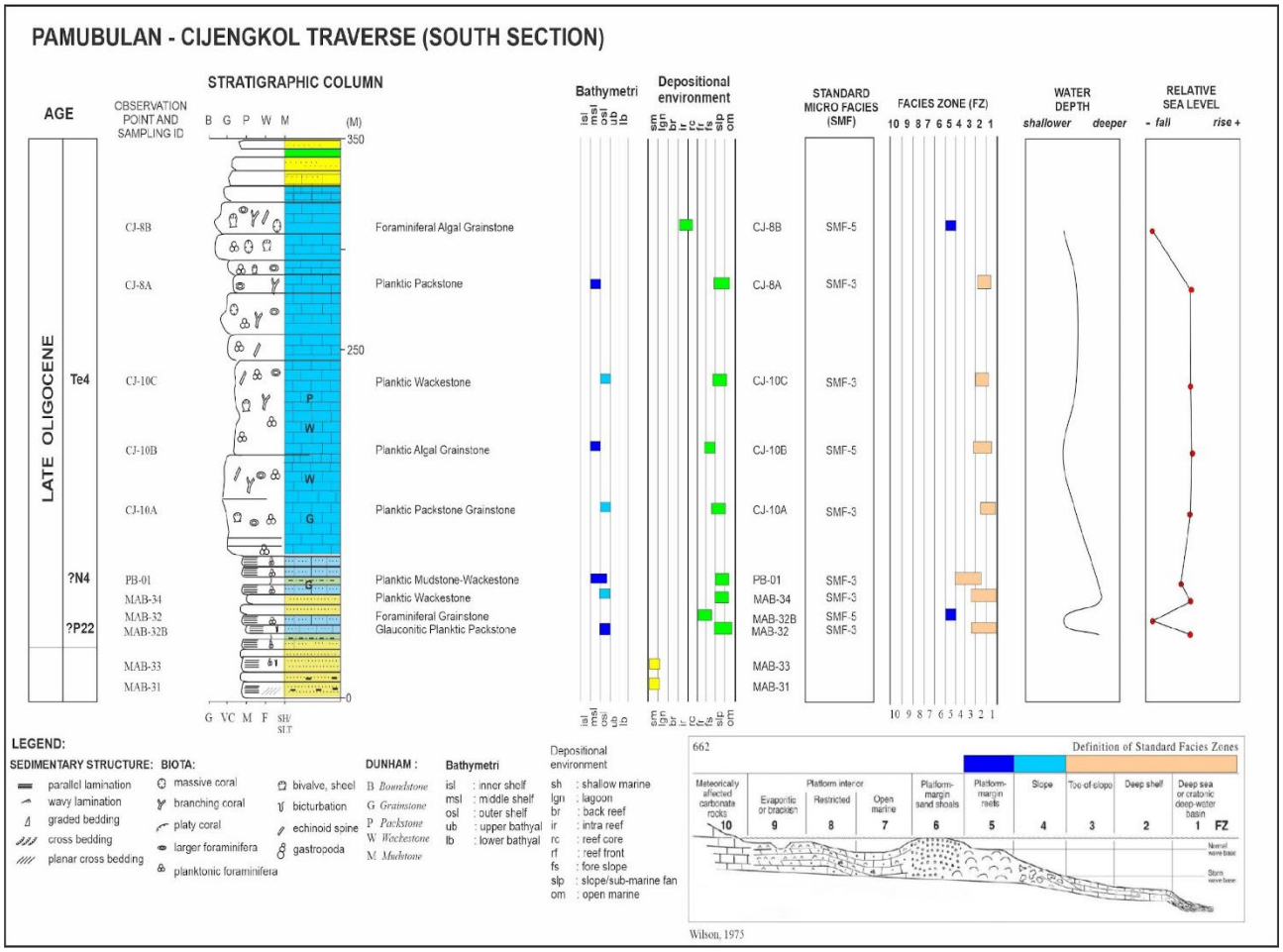


Figure 7: *Stratigraphic column from Pamubulan – Cijengkol traverse. Age and the depositional environment from biostratigraphy analysis were also plotted as well as interpretation of facies zone and relative sea level fluctuation. Water depth and relative sea level chart were plotted relatively based on benthic foraminifera content and outcrops data.*

algae. Minor dolomite was observed as calcite replacement within the matrix. *Milliolids* as back reef / restricted marine indicators are present.

In Pamubulan village, microfacies 1 (Globigerinid wackestone-packstone) is commonly observed. Laterally, this facies has deeper depositional environment compared to the western part of the area. The presence of planktonic foraminifera indicates an open marine depositional environment.

A bedded limestone (microfacies 10, Platy coral foraminifera algal packstone-grainstone) is overlain by thick massive limestone (microfacies 7, Coralline algal packstone-boundstone) and are observed along a beach in Karang Bokor area. This section was deposited in intra reef to reef core environment (Figure 10).

A finer bioclastic limestone alternating with calcareous shale was recognized in the eastern part of the study area (Citarate River). These rocks show a parallel bedding structure. Slump and soft sedimentary structures were also present. These rock assemblages were interpreted as turbidite in the outer shelf to the upper bathyal environment (Figure 11).

The biostratigraphy analysis results can be grouped into 3 zones (Blow's zonation) and 1 letter stage. These zones are: P22, N4 and younger than N4, the letter stage is Te4. All these zones show the age range of the latest Oligocene to very early Miocene. The age

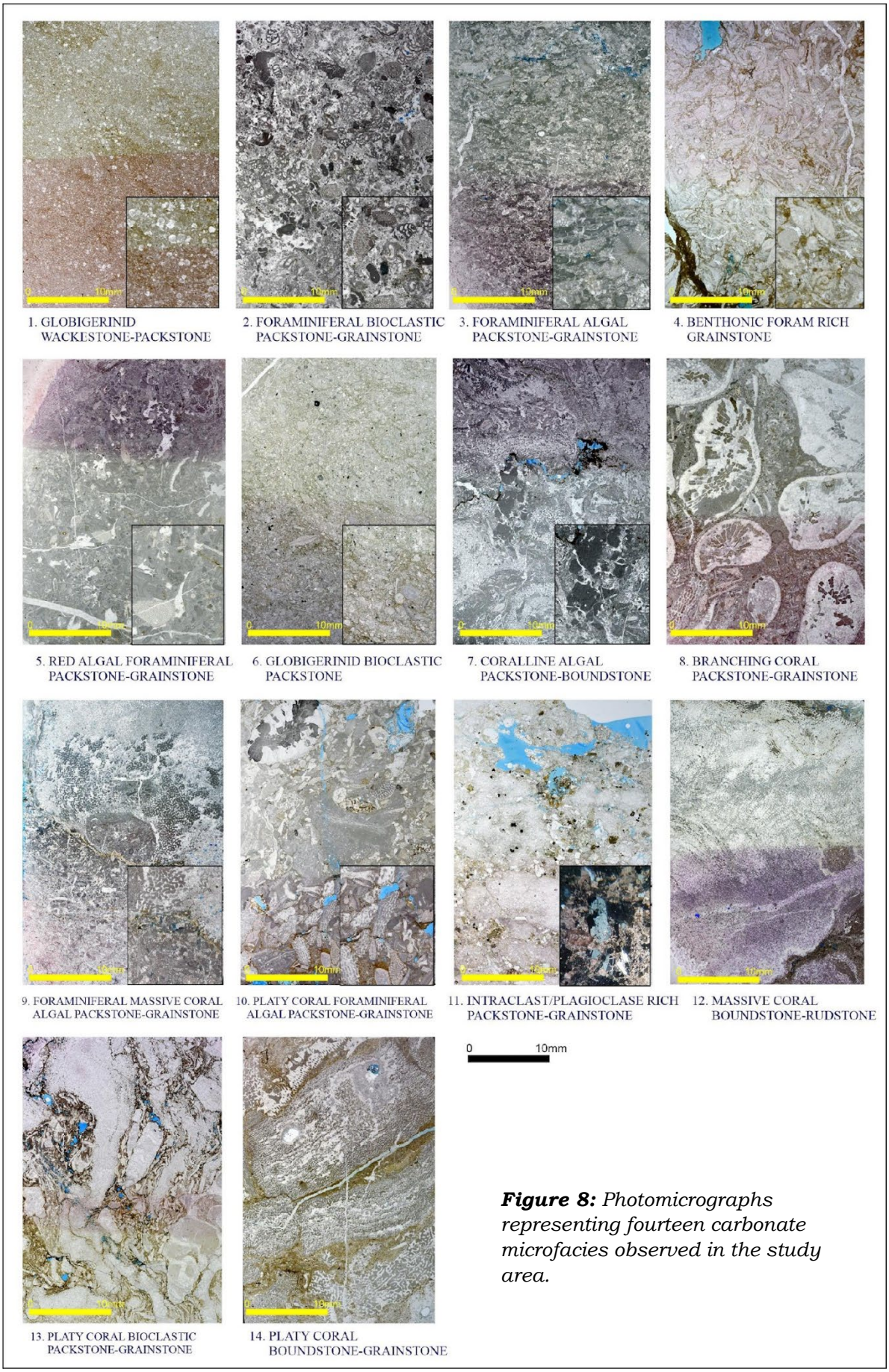


Figure 8: *Photomicrographs representing fourteen carbonate microfacies observed in the study area.*

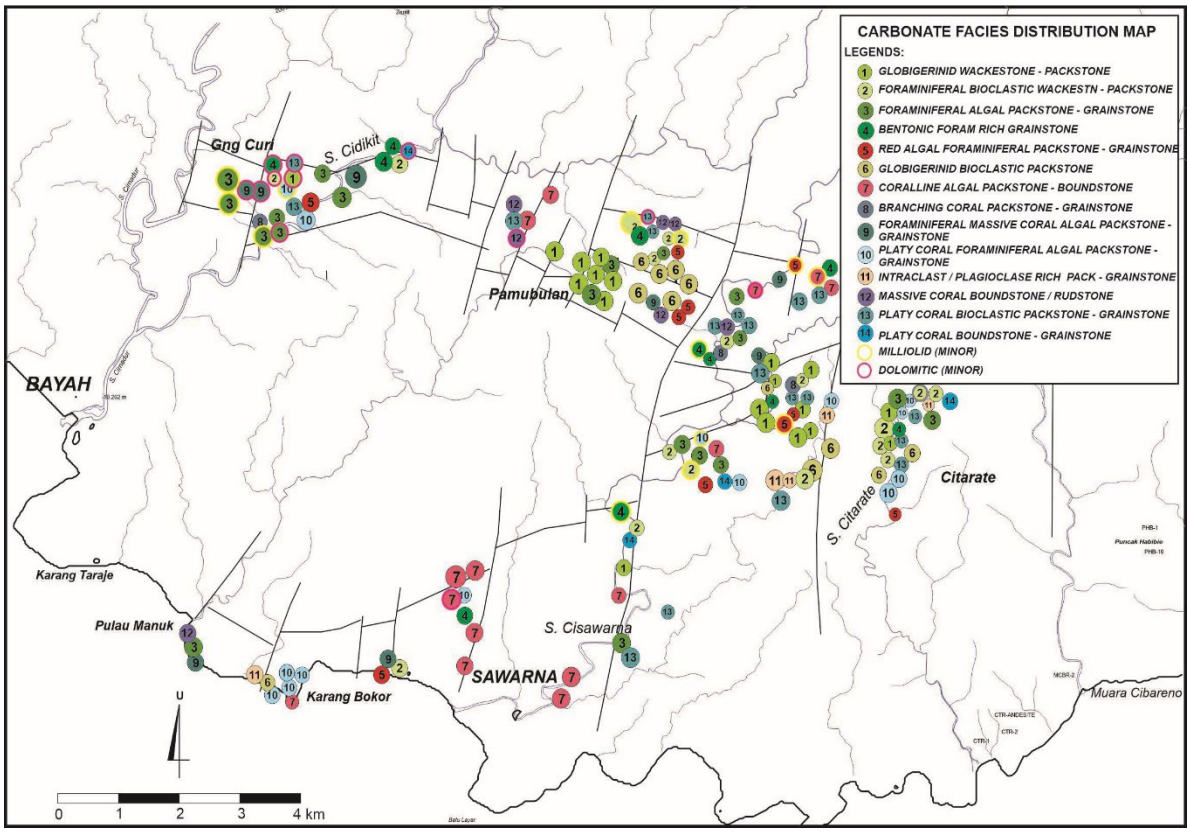


Figure 9: *Distribution of carbonate facies in study area.*

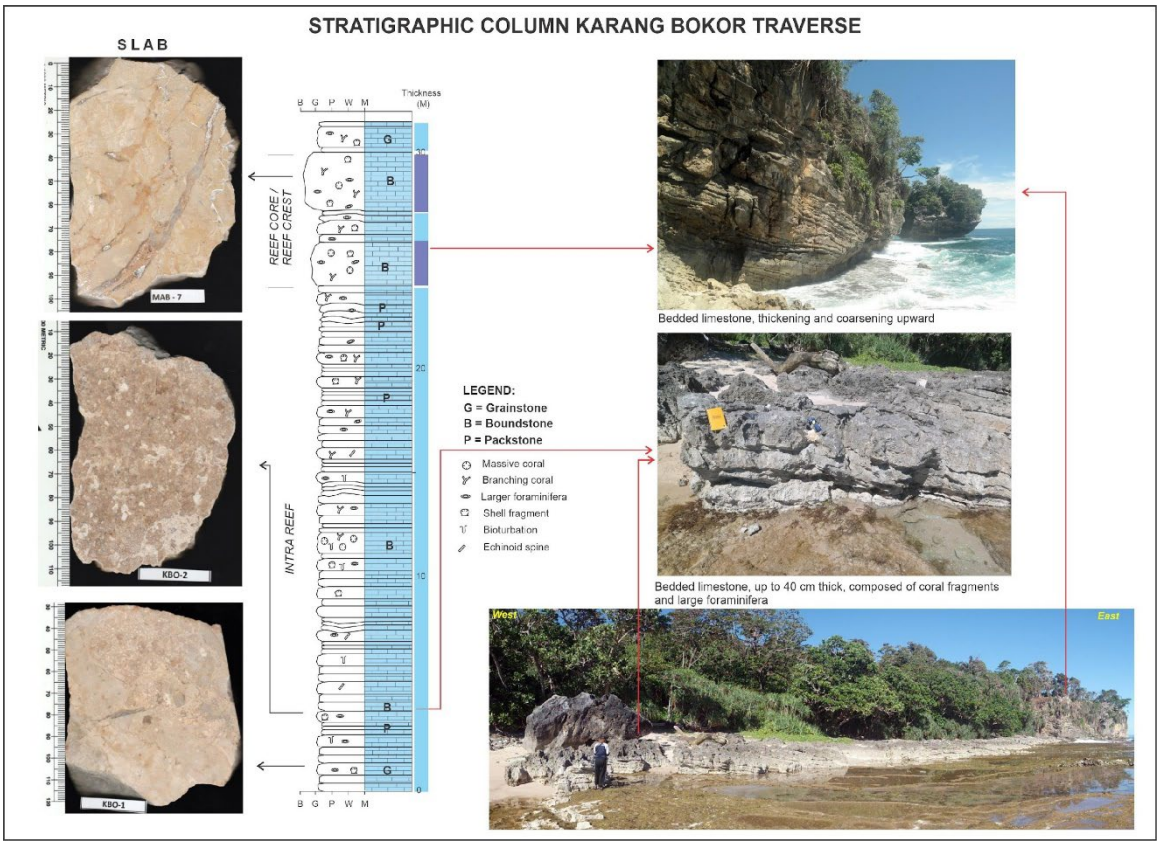


Figure 10: *Karang Bokor beach traverse (Traverse 4, Figure 2) shows a bedded limestone that is overlain by thick massive coral rich limestone. Depositional environment changes from intra-reef into reef core on the top of sections.*



Figure 11:

Calcareous shale is overlain by bedded limestone at the Citarate River, where both rocks show soft sediment deformation. This outcrop is interpreted to have been deposited in a slope environment.

zonation is then plotted on a map as shown in Figure 12.

The micropaleontological analysis of the Citarate Formation? also revealed the depositional environment and bathymetric position, ranges from inner neritic up to upper bathyal.

A detailed stratigraphic correlation was constructed using field observation data, petrographic and micropaleontology data. Wilson's Standard Microfacies model was used to interpret the depositional environment. Relative sea level rise and fall interpret based on the above data. Four marker horizons related to sea level rise were observed, which are (from old to young): green, red, magenta and blue. An E-W stratigraphic cross-section is shown in Figure 13.

From the cross-section in Figure 13, the lowest horizon (green) is dominated by interbedded calcareous sand – calcarenite – shale packages with common planktonic foraminifera. The sedimentary structure and micropaleontological content suggest an outer shelf to upper bathyal depositional environment. Micropaleontogical analysis reveals the age of this interval is P22 (Late Oligocene), based on the occurrence of *Globigerina ciperoensis* and *Paragloborotalia mayeri*. The Late Oligocene age is also supported by the occurrence of larger benthonic, *Neorotalia mecatepecensis* (Te4 and-or older). At green to red datum interval, the depositional environment varies, reef to back reef environment is common in the north-northwest area (Pamubulan, Cidikit, Gunung Curi), however, the facies changes into the deeper depositional environment (slope, toe of slope) toward the east (Lebak Tipar, Citapen and Citarate River). At the top of the interval, the marine incursion is observed in the western area indicates by thin mudstone to wackestone containing planktonic foraminifera.

Red to Magenta interval correlated with N4 (Early Miocene), based on planktonic foraminifera, by the presence of markers, including *Globigerina ciperoensis* and *Globigerinoides primordius*. Reef core and intra-reef depositional environments are observed on the western side of the study area. Towards the East, the depositional environment is getting deeper to the fore slope – slope - toe of slope deposits. Thin alternating calcareous sand and shale with soft sedimentary deformation found in the Citarate River, indicate a slope depositional

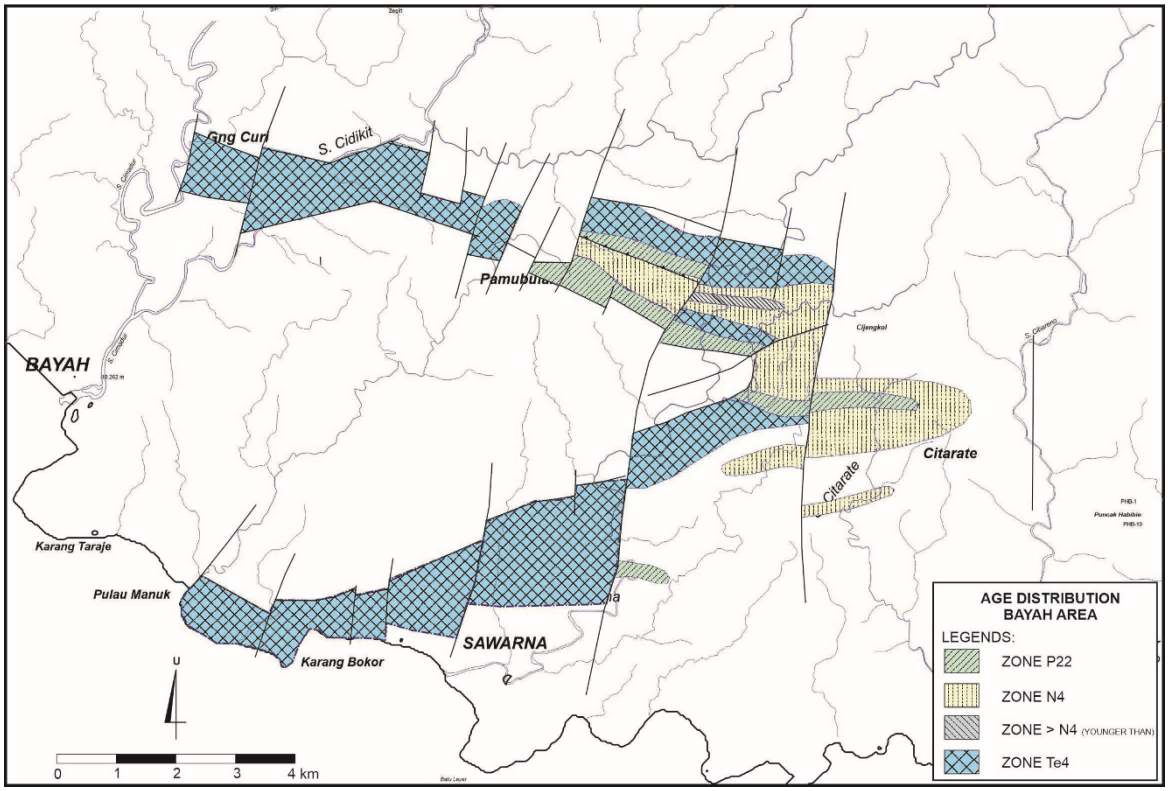


Figure 12: *Age zonation map, of the carbonate within the Citarate Formation.*

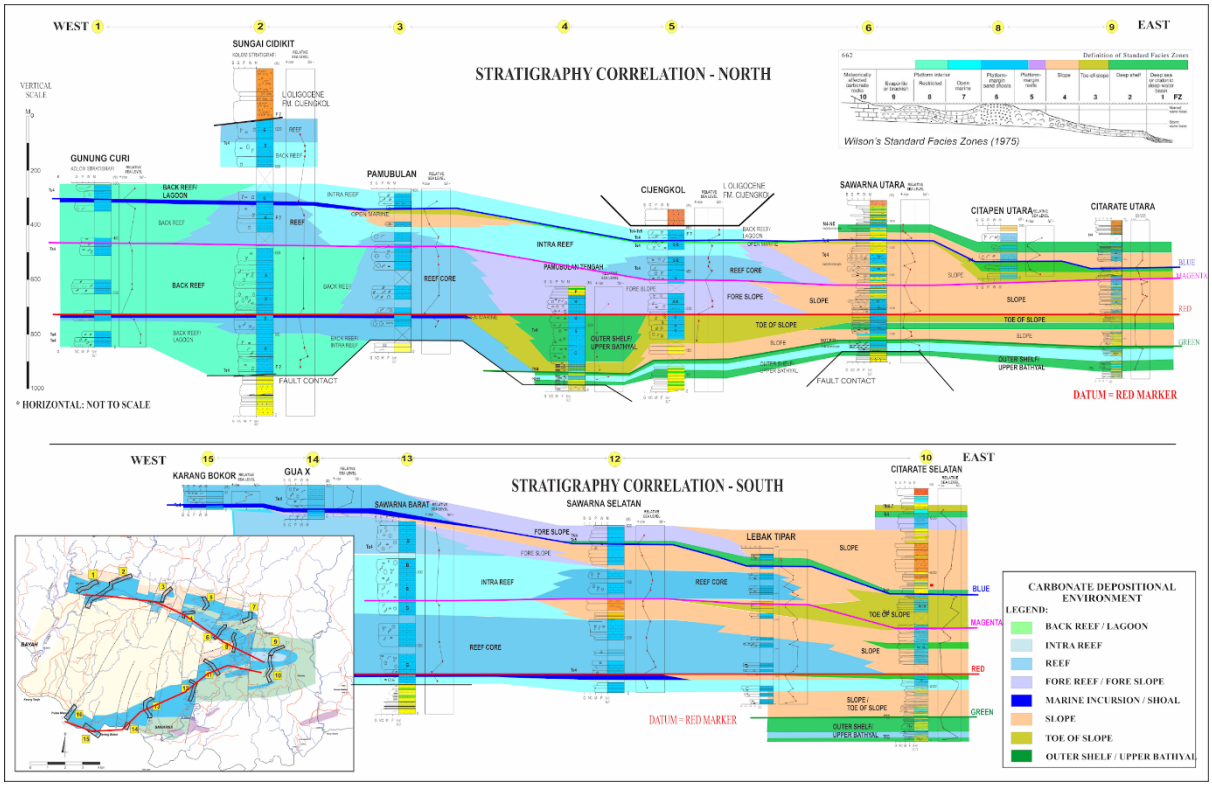


Figure 13: *West – East stratigraphic cross section showing carbonate rocks in the northern and southern part of Bayah Area. Note: on the northern correlation there is a locally upper bathyal environment in column 4, interpreted as local deep that is open to the north.*

environment. The top interval (Magenta to Blue) is almost identical to the previous interval. However, the marine incursion is detected at the top of the interval.

STRUCTURAL GEOLOGY

Koolhoven (1933) identified N-S trending fault and E-W fold series around the Bayah Dome (Figure 4). Martodjojo (1984) noted that the N-S trending structures found in Bayah to Pelabuhan Ratu in the southern part of West Java have similar orientation to those in the Kepulauan Seribu, offshore northern part of West Java. This trend is called the Sunda Trend. Sribudiyani et. al. (2003) shows that N-S structural trending in West Java was found both on the surface and subsurface (Figure 5).

The N-S trending faults are visible on the outcrops, for example a fault plane with an orientation of N 010° E has been identified in Karang Bokor area. A lineament analysis based on Digital Elevation Model (DEM) data showed that the N-S lineaments are dominant in Bayah area (Figure 5).

PALEO-ENVIRONMENT INTERPRETATION

Paleo-environment maps were reconstructed based on data integration in this study. In the lower part, the paleoenvironment map represents Magenta to Red datum interval (latest Oligocene-Early Miocene; Figure 14), back reef environment found in Gunung Curi – Cidikit River in the western part of the study area. Reef build-up was observed in Pamubulan and Sawarna areas. The depositional environment gets deeper toward east.

The second map is paleoenvironment of Blue – Magenta datum interval (Early Miocene, Figure 15). This map indicates that the carbonate reef predominantly developed on the western side of the study area. Reef cores were found on both sides of Bayah High, in the northern (Cidikit River, Pamubulan) and southern areas (Pulau Manuk, Karang Bokor). The reef is composed predominantly of branching coral, platy coral and massive coral, bounded by algae.

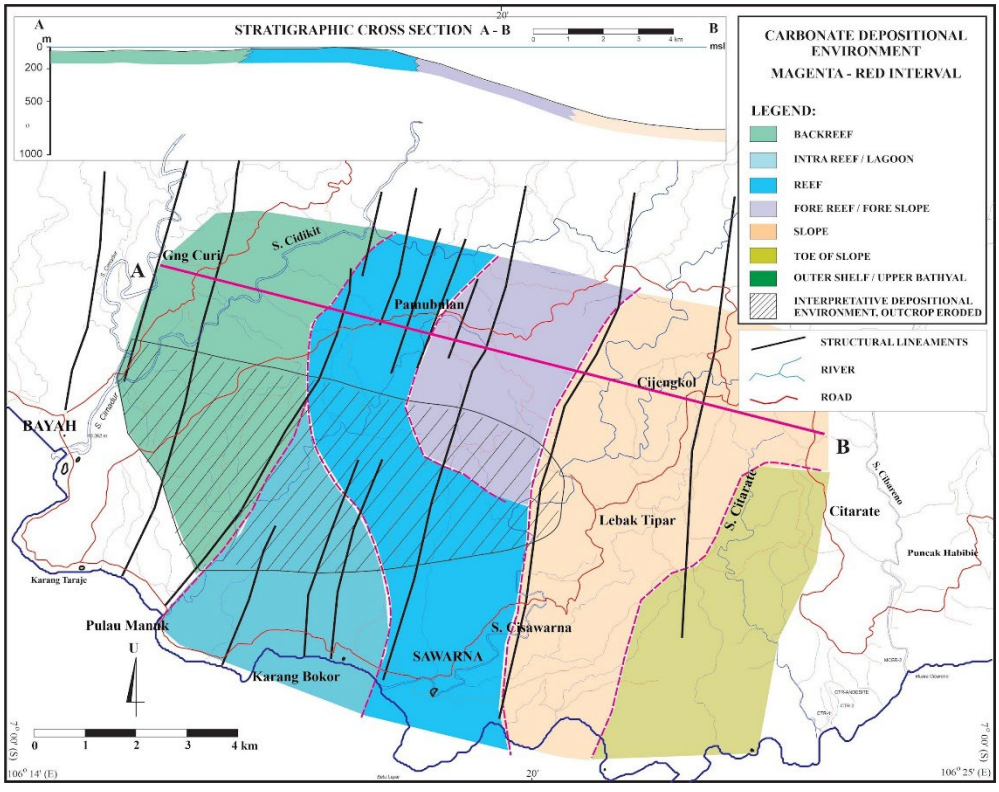


Figure 14:

Paleogeography of Bayah area at Magenta - Red Interval (latest Oligocene – Early Miocene).

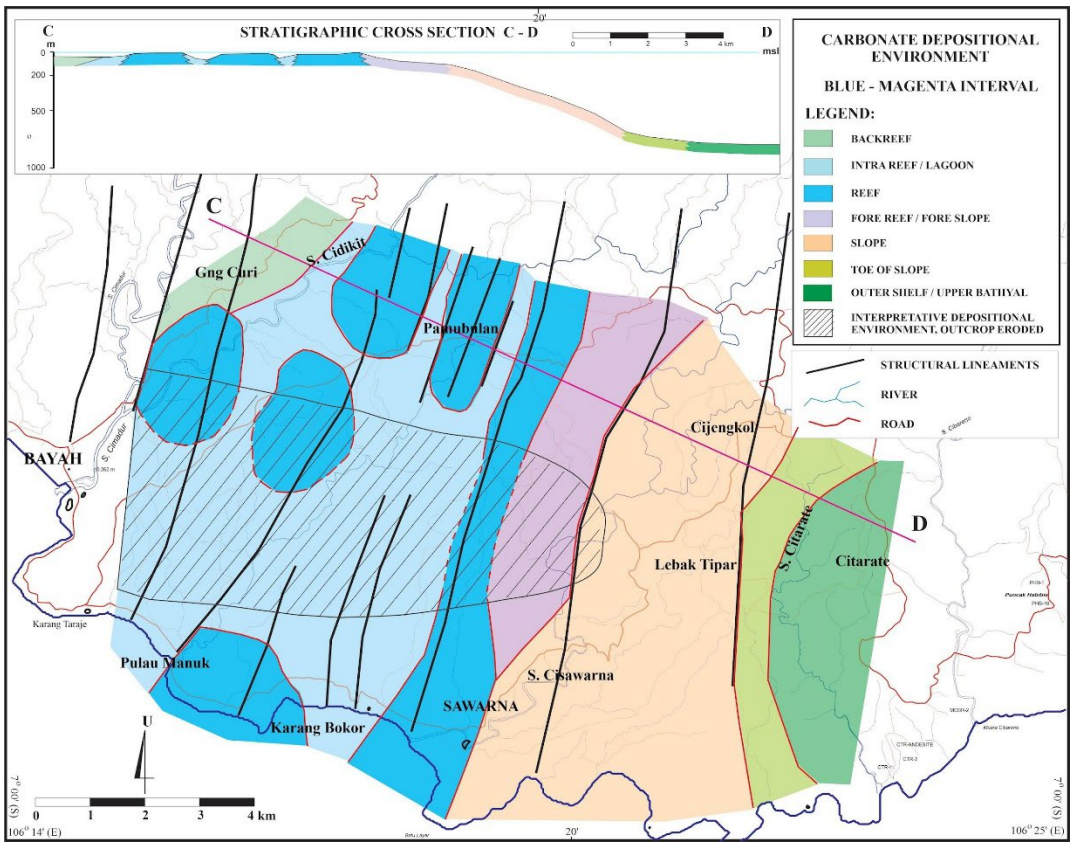


Figure 15: *Paleogeography of Bayah area at Blue-Magenta Interval (Early Miocene).*

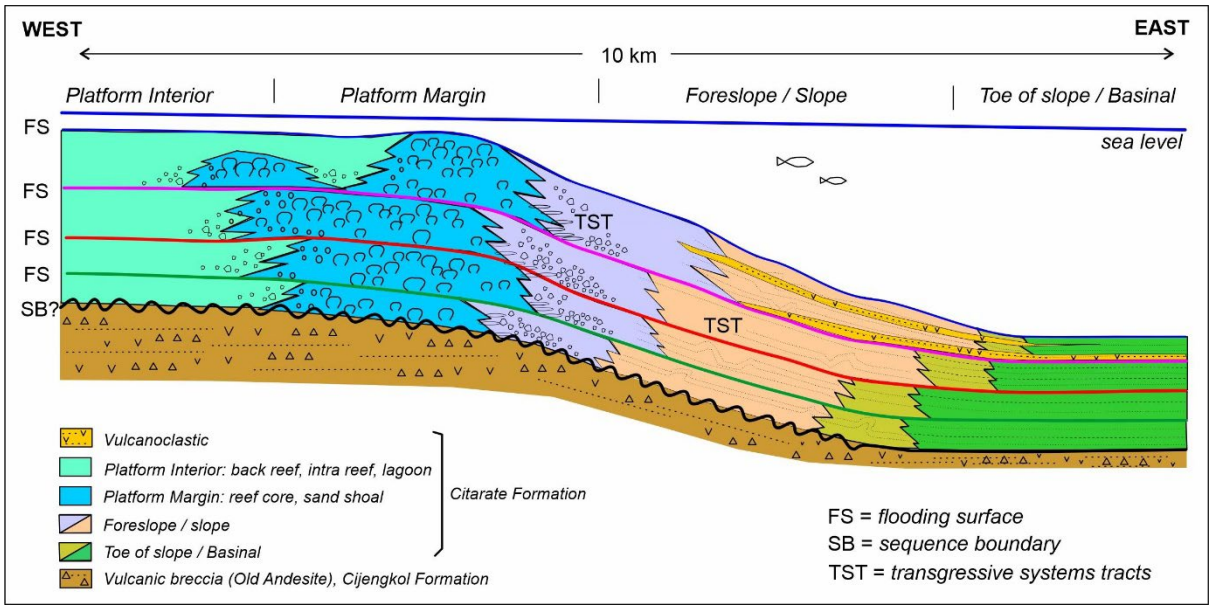


Figure 16: *Simplified west-east cross section shows carbonate depositional environment development in Bayah area.*

On the western side, at the northwest corner, a back reef environment was observed. *Milliolid* is common, minor dolomite is also present. The rock is mostly mudstone to wackestone in depositional texture.

A deeper section (fore reef, slope and upper bathyal) was found on the eastern side of the study area (Lebak Tipar, Citarate river). Bedded limestone with slump features is commonly observed in this section.

Both maps and the stratigraphic cross sections show carbonate development orientation trending north-south. A simplified west-east cross section shows depositional environment with sequence stratigraphic nomenclature is shown on Figure 16.

CONCLUSION

There are 14 (fourteen) carbonate microfacies of the Citarate Formation observed in the study area. The facies depositional environment varies from lagoonal – backreef, reef core to slope and upper bathyal.

Micropaleontological analysis reveals P22, N4, and younger than N4 (Blow's zonation, 1979) and Te4 (Adam's letter stage, 1984). This zonation corresponds to the Late Oligocene to Early Miocene age.

Based on Citarate Formation carbonate facies distribution in the Bayah area, it appears that the N-S trending carbonate body is controlled by a structural trend. Facies distribution also shows that there are paleo highs and lows within this area. The paleo relief indicates the occurrence of a relatively steep angle of deposition within a small area, from the inner shelf in the west to the upper bathyal in the east.

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