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RESEARCH ARTICLE

Diagenesis Study of Jatiluhur Formation at Cipamingkis River, Bogor Regency, West Java, Indonesia

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Abstract

Diagenesis studies in the Jatiluhur Formation are still relatively new, especially in the Cipamingkis River. This research can provide information in the form of components and characteristics of sandstone in the Jatiluhur Formation which can be used as a basis for further research or useful information in the oil and gas industry. Knowledge of diagenetic could be one of the factors that affect in raservoir quality, espesially in sandstone. In this study, data collection was carried out through surface mapping, which is 55 rock samples were obtained from stratigraphic measuring section with a path length of ±2 Km in the Cipamingkis River. The data is in the form of information on sedimentarry structure, textures and composition. There were 23 sandstone and 2 limestone samples which were then subjected to petrographic analysis, X-ray diffraction (XRD) and scanning electron microscopy (SEM). The results of study are several features of diagenesis were found including compaction that works in the form of point contact, long contact, concavo-convex contact and suture contact and dominated by mechanical compaction, while in limestone there is a brittle fracture feature in bioclasts. The cement found in the form of calcite cement, quartz and clay minerals that the form of kaolinite, smectite and illite, while the limestone is in the form of blocky and fibrous to bleded which is filled with calcite minerals. Dissolution occurs in the minerals of quartz, feldspar, and mica. The mineral replacement that is commonly found occurs in quartz and feldspar minerals. In limestone, there is an intergranular micritization. The dominant type of porosity found was interparticle with an average of 10.4% found between 3 – 23%. The history of diagenesis that occurs in rocks in the Jatiluhur Formation begins with the initial deposition of eogenesis, followed by burial mesogenesis and ends with telogenesis which reveals rocks on the surface.

Keywords: Diagenesis features, Diagenesis history, Jatiluhur Formation, Petrography, XRD, SEM

1. Introduction

The Cipamingkis River is part of the Jatiluhur Formation which is exposed to the surface. Administratively, the Cipamingkis River is located in Jonggol District, Bogor Regency, West Java (Fig. 1). The Jatiluhur Formation in naming the subsurface lithostratigraphic unit in the West Java Basin is called the Cibulakan Formation, this formation has an important role in the hydrocarbon field (Abdurokhim, 2017). In other words, the Cipamingkis River can be analogized as a representative of the reservoir in the Upper Cibulakan Formation.

Diagenesis is defined as a change in the physical and chemical characteristics of sediments after being deposited or buried (Milliken, 2003). Diagenesis consists essentially of a broad aspect of physiochemical and biological processes after deposition, when primary and interstitial mineralogy react to achieve textural and geochemical equilibrium with their environment (Curtis, 1977). In the petroleum industry, diagenesis can provide information on the distribution of porosity in sandstones to control hydrocarbon migration pathways (Worden & Burley, 2003).

Studies on diagenesis in the Jatiluhur Formation are still relatively new, especially in the Cipamingkis River. Research that has been carried out in the Jatiluhur Formation, especially the Cipamingkis River, includes a study of the genetics of mixed siliciclastic and carbonate rock deposits by Abdurrokhim and Ito (2013), the stratigraphic sequence of the Jatiluhur Formation by Abdurrokhim (2013) and a study of rocks originating from tectonic arrangements in sandstones in the Jatiluhur Formation by Rahman et al (2019). Based on the previous research mentioned above, the author will research on diagenesis in the Jatiluhur Formation which has never been published before. Research on diagenesis can provide information in the form of components and characteristics of rocks in the Jatiluhur Formation which can be used as a basis for further research or useful information in the oil and gas industry.

The purpose of this study was to find out how the diagenesis features developed in a stratigraphic meansuring section of sandstones and limestone that exposed in part of the Cipamingkis River through data collection using surface mapping methods and explain the history of diagenesis in the Jatiluhur Formation.

2. General Geology

The Jatiluhur Formation is included in the Bogor Basin which is currently in a volcanic back arc setting (Hall & Morley, 2004) as a response to subduction between the Eurasian and Indo-Australian plates which are on the southern edge of the Eurasian plate. This basin developed as a result of its flexibility to volcanic arc loading (Waltham et al, 2008). Since the Pliocene, the Bogor Basin has become part of the volcanic order in the Sunda-Java arc-trench system, and as a whole has been influenced by the comparative tectonic regime and has led to the development of thrust faults and fold axes with an east-west trend (Abdurrokhim & Ito, 2013).

The Jatiluhur Formation is composed of siliciclastic rocks and intercalated by limestone in a slope-shelf system or continental shelf environment with Middle Miocene to early Late Miocene ages (Abdurrokhim & Ito, 2013). According to Martodjojo et al (2003) this formation is covered by limestones of the Klapanunggal Formation in the north. Then the southern part is covered by deep sea deposits which are the Cantayan Formation (Sudjamiko, 1972). Limestone by the Klapanunggal Formation and deep sea deposits by the Cantayan Formation are covered by claystone which is the Subang Formation (Fig. 2).

Fig 1. Location of Research Area; (left) Map of the Cipamingkis River (Google Earth, 2021); (right) West Java Province Administration Map (jabarprov.go.id).

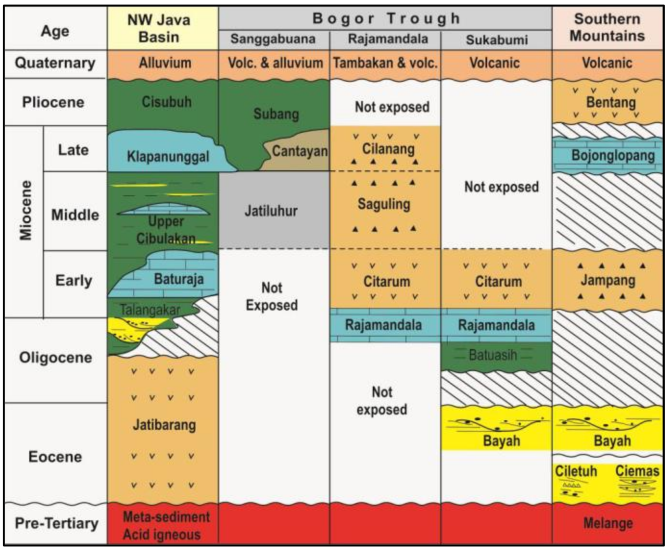

Fig 2. Cenozoic Stratigraphy in the Bogor Basin and North West Java (left) modified from Sujanto and Sumantri (1977), Martodjojo (2003), Suyono et al (2005), Abdurrokhim (2017).

3. Methods

The data collection was carried out by measuring the stratigraphic section (measurement section) measured from the south of the Cipamingkis River to the north (Fig. 2). The total length of this measurement is ± 2.5 km. Then corrections are made to get the actual thickness of the section, which is ± 100 m. Rock sampling was carried out on each representative facies in measuring the stratigraphic section. Then obtained 56 rock samples consisting of siliciclastic sedimentary rocks such as claystone, siltstone, sandstone and limestone. While the sandstone obtained as 25 samples in this measurement.

A total of 23 sandstone and 2 limestone samples were made into thin section and given bluedye solution on the sandstone samples meanwhile red alizarine solution on the limestone samples, using a polarizing microscope with observation methods in the form of Plane Polarized Light (PPL) and Cross Polarized Light (XPL). This analysis was conducted to determine the rock facies microscopically, mineral content, porosity, and other diagenesis features. XRD analysis was carried out on 4 sandstone samples using the Rigaku Smartlab device with theta angles between 5° to 65°. This analysis was to determine the dominance of primary minerals and clay minerals contained in these rocks. SEM analysis was carried out on 2 sandstone samples using a Phenom ProX device that operates at an accelerating voltage of 15 kV. This analysis to determine the detail of mineral morphography and porosity in sandstone (Fig 3).

4. Result

4.1 Compaction

Compaction occurs as a response to the compaction of sandstone due to the load on it during the burial process, causing increased contact between grains (Worden & Morad, 2003). Through thin section analysis, sandstone samples were observed based on the contact between grains consisting of point contact, long contact, concavo-convex contact, and suture contact (Fig. 4 A). By looking at the dissolution that occurs in quartz and feldspar minerals, as well as the intensity of compaction in mica minerals, we can show the type of compaction process that works on these rocks (Schmidt & MacDonald, 1979).

Based on petrographic analysis, it was found that point contact and long contact type were found in all sandstone samples in the Jatiluhur Formation. These two types of contact indicate the occurrence of mechanical compaction that occurs between quartz mineral fragments. In the concavo-convex contact type, almost all sandstone samples were found, but for suture contact it was only found in eight sandstone samples. The existence of the suture contact type is one indication of the chemical compaction process, so that the sandstone samples that have this type can be classified into rocks that have undergone a chemical compaction process. In the limestone samples in this section, the compaction that occurs due to burial is characterized by brittle fracture grains and tighter inter-grain relationships (Fig. 4 B).

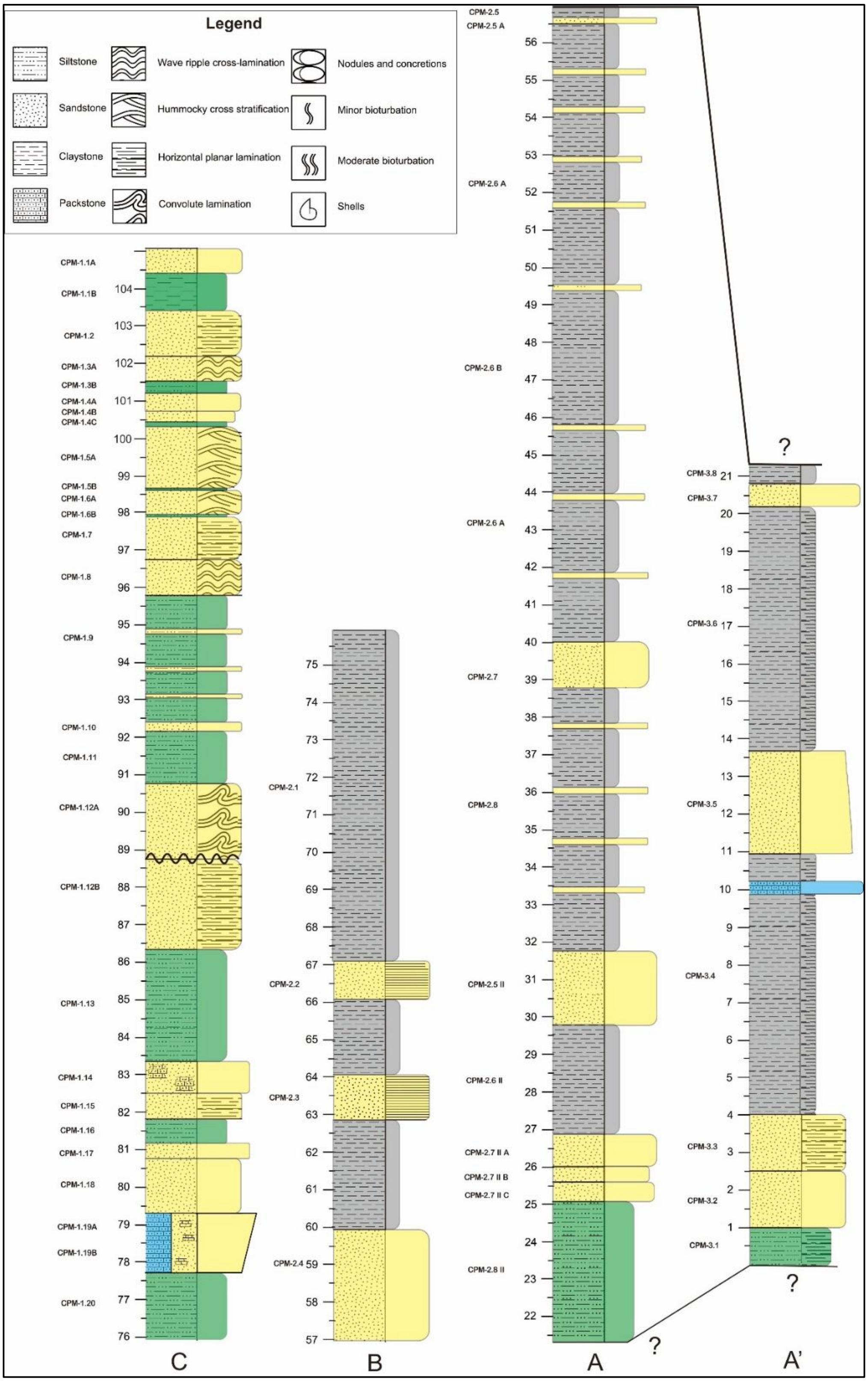

Fig 3. Stratigraphic logs of the Jatiluhur Formation in measuring stratigraphic section with a layer thickness of ±100 m at the Cipamingkis River.

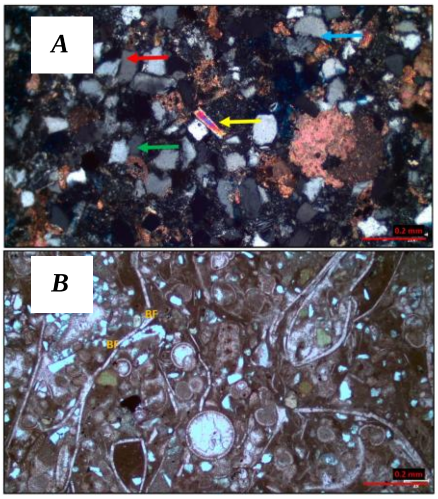

Fig 4. (A) The petrography of CPM-2.5 II consists of point contact (red arrow), long contact (yellow arrow), concavo-convex contact (green arrow) and suture contact (blue arrow); (B) The compaction of the CPM 3.4 sample (BF: brittle fracture), shows that some of the algae bioclasts have brittle fracture, thus showing discontinuities.

4.2 Cementation

After seen through a thin section, quartz cement was found in almost all of the sandstone samples. The quartz cement was found in the vicinity of the quartz fragments that looked like the result of the dissolution of the mineral (Fig 5. A). Quartz overgrowth that occurs in quartz minerals generally has a thickness equal to the thickness of the layer formed on quartz grains (Waugh, 1971). Quartz cement generally occurs during burial in the diagenesis process with temperatures above 70°C (Bjørlykke & Egeberg, 1993).

Calcite cement generally has the property of filling pores or spaces between particles locally (Worden & Morad, 2003). It's presence was found in almost all of the samples. Calcite cement was seen filling the intergranular space in most of the samples (Fig 5 B). In addition, calcite cement was also found around dissolved quartz and feldspar minerals (Fig 5 C). The cementation that occurs in limestone samples has a pore-filling character in the form of intergranular and moldic filled with calcite carbonate mineral. The calcite cement showed a blocky and fibrous to bladed morphology (Fig 5 D-E). Based on SEM analysis, it was found that cement is made of clay minerals including kaolinite, smectite, and illite-smectite. Kaolinite cements are generally present as pore fillers and sometimes appear as replacement minerals (Chima et al, 2018). At low pH conditions, water with low ionic content and the occurrence of weathering processes also early diagenesis can trigger changes in feldspar minerals to clay minerals like kaolinite (Worden & Morad, 2003). Kaolinite has a hexagonal euhedral crystal morphology that is thin and arranged like a stack of books and its presence is not spread, but only centered at several points (Fig 6 A). The presence of kaolinite can be a marker of the early phase of diagenesis (eodiagenesis).

Albite cement is also found as euhedral character that fills the rock pores. In this sample (Fig 6. B) it can be seen that albite crystals have a low enough relief so that it can be estimated that these crystals fill the pores in the rock. Albite is basically formed when detrital K-feldspar or calcitic plagioclase is replaced by albite (Ramseyer et al, 1992).

The interlayer cement in the form of a mixture of illite and smectite was found to fill the rock pores (Fig 6. C). Smectite looks like a small fraction in the form of thin fibers or flakes that coat detrital grains, while illite has an elongated and needle-like morphology (Chima et al, 2018). Early weathering and water flow in the eogenetic zone can lead to the growth of smectite cement (Worden & Morad, 2003). Then smectite can undergo a progressive change to become illite at a temperature of 70 – 90 °C (Boles & Franks, 1979). Illite cement can also be formed due to changes in kaolinite with high potassium, silica and aluminum compositions (Chima et al, 2018).

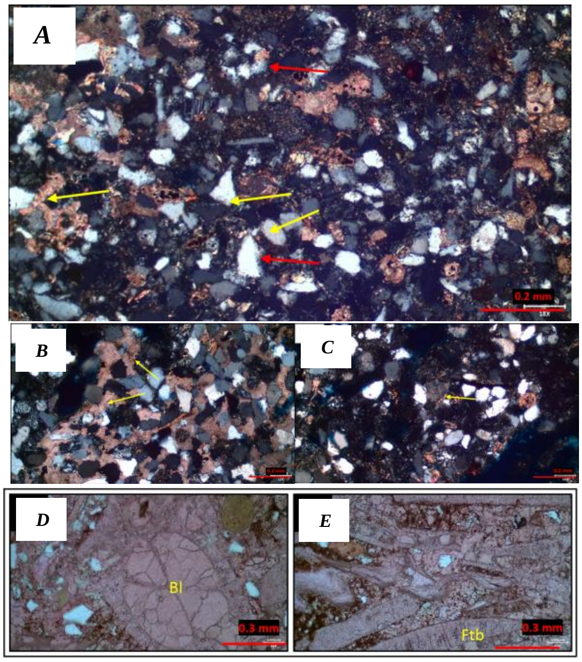

Fig 5. (A) Cementation through petrographic observations on the CPM-1.2 sandstone sample, the type of quartz cement was found which was marked with a red arrow, calcite cement that filled the interparticles and was located around the quartz grains was marked with a yellow arrow; (B) cementation of calcite interparticle filling between quartz grains; (C) calcite cementation is found around the feldspar grains; (D) in the sample CPM-1.19 A limestone in the form of blocky cementation (Bl) and neomorphism; (E) fibrous to bladed (Ftb) cementation.

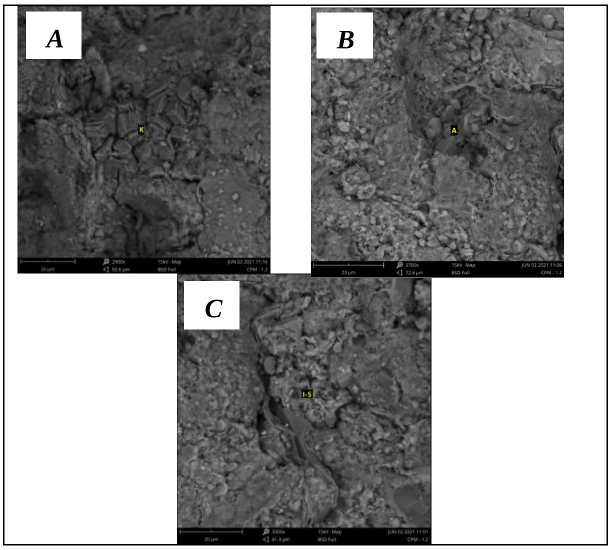

Fig 6. (A) SEM analysis on CPM-1.2 shows kaolinite (K) mineral that colonizes and fills rock pores; (B) albite minerals (A) that are euhedral in shape and fill rock pores; (C) illite-smectite (I-S) mineral which is characterized by a needle-like morphology of illite and smectite which is textured around the quartz grains.

4.3 Dissolution

The dissolution that occurs in quartz and calcite minerals is generally found as partial dissolution, where only part of the fragments undergo dissolution (Fig 7A). However, an indication of complete dissolution was found in one of the samples (Fig 7 B). This is because the shape of the isolated porosity in the matrix looks like the morphology of the quartz mineral.

Other minerals that undergo a partial dissolution process are mica and feldspar minerals (Fig 7 C-D). Dissolution of mica minerals was found in rock samples CPM-1.4 which was characterized by the presence of porosity around the mineral. Likewise with the dissolution of feldspar minerals, where porosity was found in these minerals. The appearance of dissolved feldspar in the sandstone indicates the burial depth of this rock is 1.5 to 4.5 KM, with temperatures between 50° to 150°C (Wilkinson et al, 2001).

Dissolution in limestone samples occurred in a small part in the CPM-1.19 sample. Dissolution can affect calcite cement, grains, mud matrix, to dolomite crystals (Boggs, 2013). In this sample, dissolution resulted in secondary porosity of the interparticle type and opened a space between the calcite cement and the bioclast (Fig 8 A).

The secondary porosity found in the sandstone of the Jatiluhur Formation is the result of the dissolution process of mineral fragments contained in the rock. The commonly found secondary porosity is the result of dissolution of the minerals quartz, calcite, mica, and feldspar (Fig 8 D-E-F-G). In addition, porosity with fracture type was found in several samples, this type is characterized by long and continuous porosity morphology, caused by stress experienced by the rock (Fig 8 H-I). All rock samples in the Jatiluhur Formation sandstone have primary porosity (except limestone in CPM-3.4) with an average porosity of 10.4% which is found between 3 – 23%. The primary porosity commonly found is of the interparticle type, with porosity characteristics located between fragments or inter-porous spaces (Fig. 8 B-C).

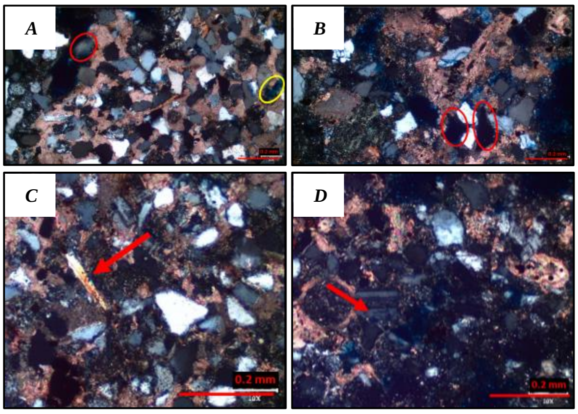

Fig 7. Dissolving features based on petrographic analysis; (A) Partial dissolution of quartz (red circle) and calcite cement (yellow circle) in sample CPM-2.7 II C; (B) complete dissolution.(red circle) on sample CPM-3.7; (C) Dissolution of mica minerals (red arrows) in sample CPM-1.4; (D) dissolution of feldspar minerals (red arrows) in the sample CPM-3.5.

4.4 Mineral Replacement

Mineral replacement in this process is defined when a dissolved mineral and another mineral are deposited in a dissolved place simultaneously (Boggs, 2013). After petrographic observations, it was found that several mineral changes occurred in the sandstone of the Jatiluhur Formation, there are the replacement of quartz minerals by calcite minerals, replacement of feldspar minerals by calcite minerals and changes in the clay matrix by carbonate minerals (Fig 9 A-B-C).

In limestone samples, the micritization process is common in both limestone samples. The greatest abundance of micritization was found in the limestone samples from CPM-3.4 (Fig 10). Micritization is generally found in the inter-grain matrix and a small portion is found enveloping the grains or at the edges of the preserved fossil grains with a dark brown color. Intensive micritization will usually occur in some warm water environments so that the carbonate grains are reduced almost completely to micrite (Boggs, 2013).

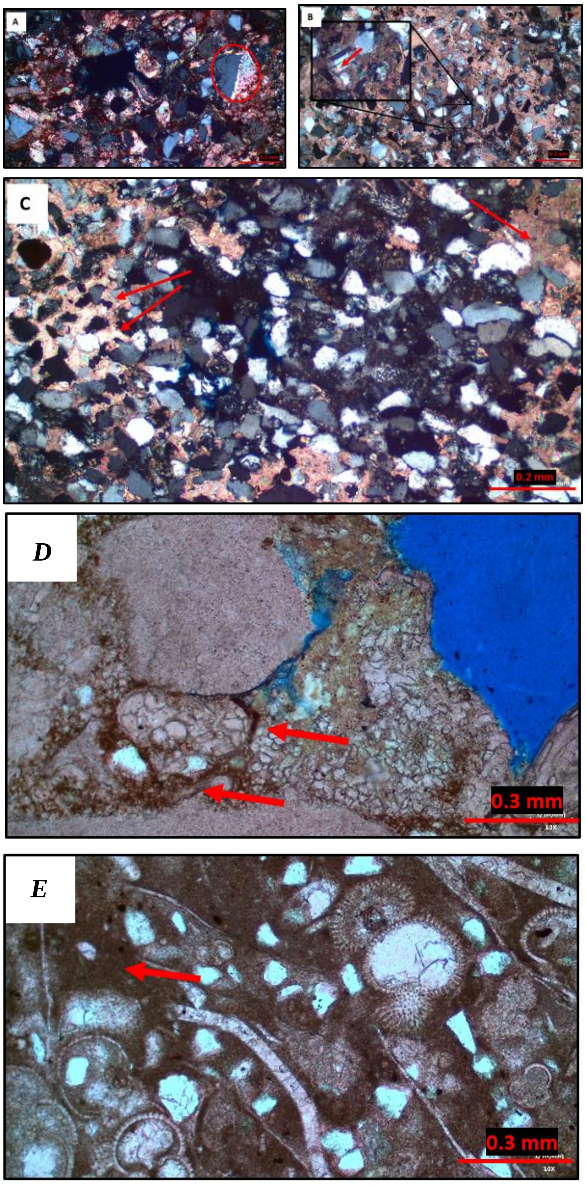

Fig 8. Mineral replacement; (A) Quartz change by calcite cement (red circle) on CPM-3.2; (B) replacement of feldspar by calcite cement (red arrow) on CPM-1.4 A; (C) Substitution of matrices by calcite cement (red arrow) in CPM-1.2 samples; (D) Mikritization in CPM-1.19 A samples A mikritization occurs around the Bioclast grain; (E) mikritization occurs in the matrix between grains in the CPM-3.4 sample

4.5 Diagenesis History

Eodiagenesis

Eogenesis is defined as the early diagenesis stage where the processes operating at this stage are largely controlled by the depositional environment (Berner, 1980). Generally, the maximum depth of eogenesis is 1 – 2 km with temperatures between 30° – 70° C (Morad et al, 2000). The dominant process working at this stage is compaction due to early burial. At this stage the rocks in the Jatiluhur Formation were deposited in a shallow marine environment and slowly buried. Birnessite mineral from XRD analysis is one of the environmental markers of deposition of sandstone in the Jatiluhur Formation. Birnessite mineral is formed due to the deposition of nodule concentrations formed in the sea (Burns, R.G. & Burns, V.M, 1977). In addition, the gluconite mineral found in the petrographic analysis in the CPM-3.4 sample indicates a depositional environment that occurred in the marine environment.

The compaction process that works dominantly at this stage is the rearrangement of grains which is marked by point contact on contact between grains (Fig 4 A). Most of the sandstones through petrographic analysis show a point contact which then develops into a long contact at a deeper environtment. Several clay minerals that are early markers of early stage diagenesis were found in the SEM analysis, such as kaolinite and smectite minerals. Kaolinite can be present at this stage as a replacement ofthe mineral feldspar which is unstable at increasing pressure and temperature.

The formation of autigenic gluconite minerals occurs in open-shelf environments deeper than 50 m, under sub-oxic conditions between the sediment bed surface and water (López-Quirós et al, 2019). This condition occurs due to low sedimentation rates and subsurface current activity that leads to sediment deposition (López-Quirós et al, 2019). In marine environments with redox conditions (low oxygen) generally occurs the formation of pyrite with a distinctive morphology (Boggs, 2013). Pyrite minerals can form as cement or replace other materials (Boggs, 2013).

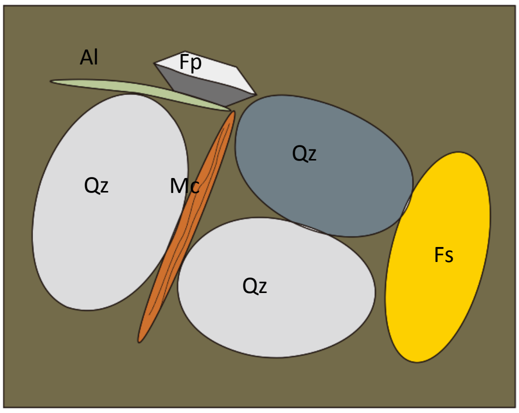

Fig 10. Illustration of the initial deposition process at the Eogenesis stage by producing point contacts and long contact due to loading of sediments on top (Qz: quartz, Fs: fossils, Fp: feldspar, Mc: mica, Al: algae).

Mesodiagenesis

Diagenesis stage after eogenesis is mesogenesis (Morad et al, 2000). This stage is defined as a diagenesis process that occurs during burial that is not influenced by the depositional environment and it is the initial stage of metamorphism (Worden and Burley, 2003). Most of these regimes occur at depths of 100 – 1000 m with temperatures of 200° – 250° C (Worden & Burley, 2003). Due to the load of the overlying rock during the burial process, the compaction process in this regime occurs more intensely, which is characterized by the appearance of concavo-convex contacts to suture contacts that can be seen through petrographic analysis (Fig 4. A). In the CPM-3.4 sample, found bioclasts that have brittle fracturing due to this compaction process (Fig 7. A-B-C-D). In the CPM-2.2 sample which was carried out by XRD analysis, it was found that the mineral faujasite was generally formed at a temperature of 100° - 200°C, indicating that the burial process at this stage was around that temperature.

As the temperature increases, some minerals that are unstable under certain conditions will eventually dissolve to turn into other minerals. One of the dissolving processes that occur is in feldspar minerals which are unstable at certain pressure and temperature conditions and then turn into albite clay minerals. Smectite mineral which have continue to increasing pressure and temperature also slowly turns into illite based on SEM analysis on sample CPM-1.2. Other dissolution also occurs in quartz and calcite minerals are generally found as partial dissolution (Fig 7). However, an indication of complete dissolution was found in the CPM-3.7 sample, but could not be further identified for the type of mineral. Another dissolved mineral is mica, which results a secondary porosity (Fig 7).

Cementation also occurs at the mesogenesis stage. The dominant cements formed are calcite and quartz cement (Fig 5. A). Through petrographic analysis, most of the calcite cement was found to fill the interparticles between grains. Some of quartz cement is present by covering the quartz grains. This cement is present significantly at a temperature of 70° – 80° C (Giles et al, 2000). Other cementation was also seen based on SEM analysis, where the presence of illite-smectite cement. Smectite in higher temperature increase will be unstable, and will turn into an illite when the temperature is more than 90°C (Worden & Morad, 2003).

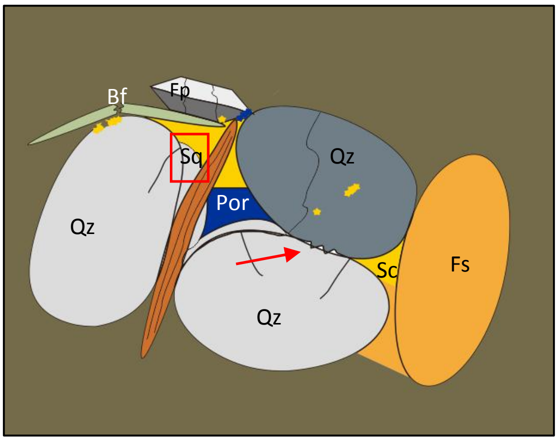

Fig 11. Illustration of the deposition process is increasingly causing the Brittle Fracturing feature, Convex Convex and Suture Contact (red arrow), as well as the coating (red box), and cementation on some items (Qz: Quartz, Fs: fossils, Mc: mica, Por: porosity, Bf: brittle fracture, Sq: quartz cement, Sc: cement calcite).

Telodiagenesis

Telogenesis is the final stage of diagenesis that occurs in rocks that have tectonic processes so that they are exposed to the surface, generally influenced by meteoric water (Worden & Morad, 2003). In addition, at this stage further dissolution occurs in mineral fragments and alteration occurs, especially in feldspar minerals (Boggs, 2013). All rock samples included in the measurement stratigraphic section in the Jatiluhur Formation are surface outcrops located on the floor and walls of the river. Some samples are indicated to have been affected by meteoric water, thereby changing some of the rock composition and the growing dissolution process (Fig 7). In the XRD analysis of the CPM-1.17 sample, Clinochlore was found. Clinochlore (Fig. 12) is a member of the chlorite mineral, which is mostly formed as a result of altered biotite minerals (Rahman et al., 2011). This indicates that the exposed rock in this sample has undergone an alteration process due to the influence of meteoric water (Fig. 13).

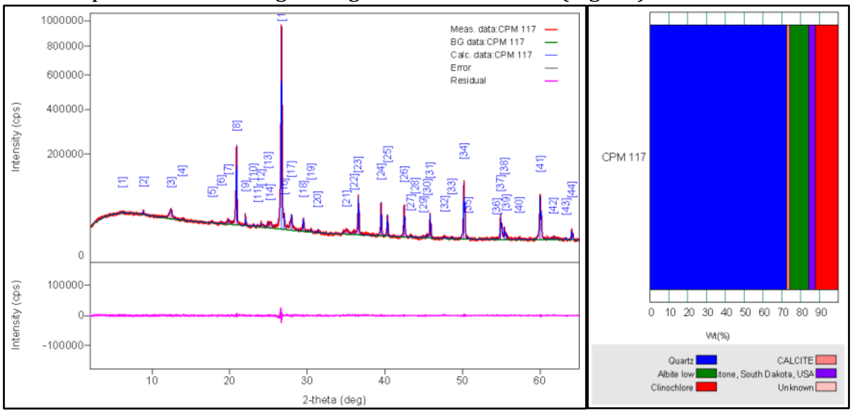

Fig 12. X-ray diffraction displays the percentage of major mineral types in CPM-1.17 samples; Mineral faction in X-ray shooting (left); The percentage of mineral compositions on rocks (right).

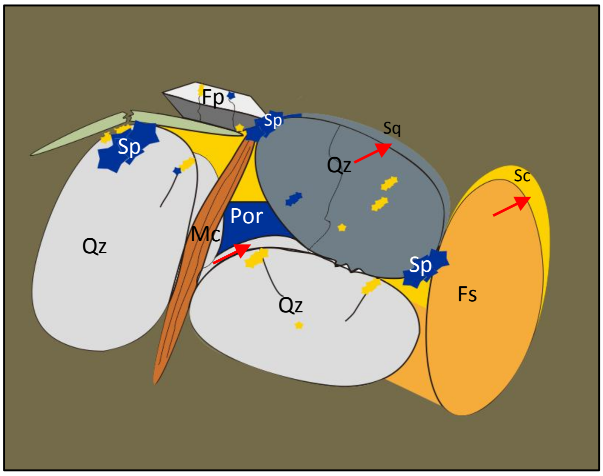

Fig 13. Illustration at the phase of telogenesis When dissolving is increasingly developing (red arrow) and produces more secondary porosity and cementation around more detrential items (Qz: quartz, Fs: fossils, Mc: mica, Fp: feldspar, Por: porosity, Sq: quartz cement, SC: cement calcite, SP: secondary porosity).

5. Conclution

1. The diagenesis features that develop in rocks in the Jatiluhur Formation are as follows:

   a. Compaction feature that works in the form of point contact, long contact, concavo-convex contact and suture contact. And dominated by mechanical compaction. The compaction on limestone samples is brittle fracture that occurs in bioclasts.

   b. Cementation found in sandstone is in the form of calcite cement, quartz and clay mineral cement such as kaolinite, smectite and illite. In the limestone, cementation is in the form of blocky and fibrous to bladed which is filled with calcite mineral.

   c. Dissolution feature was found to occur in the minerals quartz, feldspar, and mica.

   d. Mineral replacement that are commonly found are replacement in the quartz and feldspar, meanwhile in limestone, there is an intergranular micritization.

   e. The dominant type of porosity found was the interparticle type with an average porosity of 10.4% which was found to be 3 – 23%.

2. The history of diagenesis that occurs in rocks in the Jatiluhur Formation begins with the initial deposition of eogenesis, burial mesogenesis and ends with telogenesis which is exposed on the surface.

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