ARCHITECTURAL, FACIES, AND DEPOSITIONAL ENVIRONMENT ANALYSIS OF PALEOGENE TO NEOGENE DEPOSIT IN THE NORTHERN OMBILIN BASIN: IMPLICATION HYDROCARBON POTENTIAL

ANALISIS ARSITEKTUR, FASIES DAN LINGKUNGAN PENGENDAPAN PADA ENDAPAN PALEOGEN HINGGA NEOGEN DI CEKUNGAN OMBILIN BAGIAN UTARA: IMPLIKASI TERHADAP POTENSI HIDROKARBON

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ABSTRACT : Ombilin Basin is located in the intramontane zone with hydrocarbon potential. Sangkarewang, Sawahlunto, Sawahtambang dan Ombilin Formation are the subjects of the research. Literature study, geological mapping, studio and laboratory analyses which included reservoir, geochemical, granulometry, petrography, and pollen analysis were methods used to interpret the architectural and facies analysis. The Sangkarewang Formation is deposited in the lacustrine environment through suspension mechanism which consists of oxic and anoxic facies. Sawahlunto Formation is deposited by saltation mechanism, thus it is dominated by fine fraction deposits which indicates the fluvial environment (meander river), it consists of overbank, point bar and channel facies with sand bed form, and overbank fines architectural. Sawahtambang Formation is deposited in a fluvial environment (braided river) through bedload mechanism. The facies of this formation are channel and overbank facies with channel, sand bed form, and gravel bars architectural. Ombilin Formation is deposited in the marine environment through suspension current which facies are pro delta, delta front and flat tidal. The hydrocarbon system in the Ombilin Basin consists of Sangkarewang Formation as the source rock with thick black shale lithology and papery shale structure. The hydrocarbon migration consists of primary and secondary migrations. Sawahlunto Formation and Sawahtambang Formation have potential as reservoirs. Sawahtambang Formation has excellent porosity classification (27% -29%) and permeability value amount 183-284 mD. The traps of hydrocarbon system are Koto Gadang anticline and Sawahluar fault. Ombilin Formation consist of very thick of impermeable layer is potential as a seal. Further research in Ombilin Basin is required to prove hydrocarbon potential.

Keywords: Architectural, Sedimentation Facies, Hydrocarbon, Ombilin Basin

INTRODUCTION

Background

Detailed research on Tertiary strata of Ombilin Basin is great for study, especially of the Paleogen to Neogen deposit. Research area are located on the northern Ombilin Basin were focused pada Formasi Sangkarewang, Formasi Sawahlunto, Formasi Sawahtambang dan
Formasi Ombilin (Figure 1). Architectural analysis, facies and depositional environments are helpful in interpreting potential hydrocarbon implications on ombilin basins in the study area.

Architectural methods is a technique that uses data derived from outcrop profile with attention to the details of the components and the basis of the reasoning in the form of two and three dimensional an outcrop (Miall, 1996 within Fernando, et al., 2017). An architectural element may be defined as a component of a depositional system small or equivalent and larger than an individual facies unit fill the place, characterized by a distinctive facies assemblage, internal geometry, and same external form, furthermore architectural element are amenable to descriptive and genetic classification as are their component lithofacies (Miall, 1996 within Fernando, et al., 2017).

Facies are a body of rocks that can be identified and distinguished by other rock units on the basis of geometry, lithology, sedimentary structures, fossils and patterns of its ancient currents (Selley, 1985). Facies are generally grouped into facies associations that are genetically related so that facies associations have meaning as environment.

The deposition environment is a part of the earth's surface where physical, chemical, and biological processes differ from the region adjacent to it (Selley, 1988). Nichols (2009), adding that the deposition process is a process that takes place during the process of formation, transport, and sediment deposition.

**Geologi Regional**

Geologically the Ombilin Basin is a Tertiary basin located in a mountainous hill zone or also called intramontane basin bounded by Pre-Tertiary rocks at the edge of the basin. The Ombilin Basin lies in the Magmatic arc of the Barisan Mountains and the process of formation is strongly influenced by the strike slip fault of Sumatra with the south-east orientation associated with second-order descent of thrust and normal faults forming the graben structure (Koesomadinata and Matasak, 1981).

**Tectonic Regional**

Techtonophysiographically, the Ombilin Basin lies between the current volcanic arc of the western and non volcanic Barisan Mountains in the eastern Range Mountains (Figure 2). Ombilin basin is also controlled by active faults in the boundary division of the Takung Fault which is oriented WNW-ESE in the north-east and the NW-SE Oriented Fault System in Southwest (Noerardi et al., 2005).
The Evolution of Ombilin Basin is tectonically inseparable from regional tectonic mechanisms in the tectonic development scale of Southeast Asia, such as the Indian movement of the block towards the north which eventually with the Eurasian continent by forming the Himalayas, the Extrusion Concept of Tapponnier (1986), Woyla microplate with oceanic composition as the basement of the Ombilin Basin, the development of the Sumatran Fault System, the direction and speed of the Indo-Australasia plate convergence to the West-South side of the Eurasian plate, the rotation of Sumatran plate convergence to the West-South side of the Eurasian plate, the rotation of Sumatra Island, the open Andaman Sea all of which form back arc basin patterns in Sumatran basically of each other is identical as well as the Ombilin Basin. The Woyla landscape formed in the western part of Sundaland during the Mesozoic End and formed a clear boundary against the Mergui microplate (Pulunggono and Cameron, 1984). Therefore the Ombilin Basin is diverted by two types of microplate microplate continental mergui in the northeast of the basin and the Woyla microplate oceanic in the southwest (Situmorang et al., 1991).

Based on the genre of the Ombilin Basin is a pull apart basin, graben extends from the south of Solok to northwest through Payakumbuh with a length of about 120 km and on the southern part of the graben basin covered by volcanic rocks from Quaternary to Recent from Malapi Volcano, Merapi, Maninjau and Singgalang (Yeni, 2011). The compression is the product of subduction of the Indian-Australian plate under Sundaland, subduction begins in the Early Middle Eocene and creates an extensional tectonic regime that forms several grabens along the back arc tectonic setting (Yeni, 2011). The first asymmetric graben on the Ombilin Basin occurs as a result of the Tertiary Strike-slip fault of the Sumatran Fault system which then continues the dextral fault movement along the NW-SE direction forming the next graben (Situmorang et al., 1991).

**Stratigraphy**

Sedimentary rocks in the Ombilin Basin are aged from paleogene to Pliocene, consisting of sedimentary lakes, swamps and fluvial deposits, as well as marine sediments. The sedimentary rocks are lined by Pre-Tertiary rocks that are uncomfortably covered by Tertiary sediments starting from the age of the Paleogene (Figure 3). In particular, this study focused on the Sangkarewang Formation, Sawahlunto Formation, Sawah Tambang Formation and Ombilin Formation.

The Sangkarewang Formation is the oldest Tertiary sedimentary rock in the Ombilin Basin (Silitonga and Kastowo, 1973; Koesomadinata and Matasak, 1981; Koning, 1985; Moss
and Howells, 1996). The Sangkarewang Formation has a facies relationship to the Brani Formation. The Eocene of Sangkarewang Formation is a lake sediment consisting of sandstones and dark gray claystone. Based on the results of pollen analysis in the Sangkarewang Formation, it is estimated that the early Eocene (Koning, 1985), early Eocene (Yarmanto and Fletcher, 1993) (Figure 2.4).

The Sawahlunto Formation consists of river deposits and red, green and purple floodplains, consisting of rocks and shales associated with sandstone deposits, and lined with layers of precipitated coal at Eocene age. Coal layers are thickness of 15 meters and economic value (Moss and Howells, 1996). According to Koning (1985), said the Sawahlunto Formation has an unrelated relationship to the top and bottom of the Sawahlunto Formation. The deposition environment of the formation is interpreted as a meander river system with a number of lakes around the river channel (Koesomadinata and Matasak, 1981). The hiatus process was found exposed in several places and as evidence of a lack of coherence on several seismic sections on the edge of the basin. The thickness of Sawahlunto Formation reaches 274 meters (Kosoemadinata and Matasak, 1981), whereas according to Koning (1985), based on the wellbore, this formation has a thickness of 170 meters.

According to Koesomadinata and Matasak (1981), the Sawahtambang Formation is characterized by a thick, massive sequence of sandy sandstone. The shale and the rocks are growing locally. Sandstones are light gray to brown, fine grained to very coarse, mostly conglomerate with quartz sized gravel fragments, very poorly sorted, cornered, hard and massive. At the bottom of the formation there are inserts of layers of clay or shales of siltstone and forming a separate unit of the Rasau. Meanwhile, at the top of this formation there are coal deposits that occur locally and form their own units, namely Poro Members. The age of the Sawahtambang Formation is Oligocene (Koesomadinata and Matasak, 1981; Koning, 1985; Yarmanto and Fletcher, 1993; Moss and Howells, 1996). According to Koesomadinata and Matasak (1981), Sawahtambang Formation has a thickness of between 625 meters to 825 meters, and indicates the occurrence of thickening from north to south basin. The younger and rising units aligned above Members of the Lower Ombilin Formation are Members of the Ombilin Formation (Silitonga and Kastowo, 1973) also known as the Ombilin Formation (Koesomadinata and Matasak, 1981; Koning, 1985). This Ombilin Formation reaches 1400 meters thick, consisting of marine sediment in the form of gray, clay and local lies found bioclastic concrete layers (Moss and Howells, 1996). The Ombilin Formation has an early Miocene (Koesomadinata and Matasak, 1981; Koning, 1985; Yarmanto and Fletcher,
1993; Moss and Howells, 1996). The deposition environment of the Ombilin Formation is an indication of the marine environment this is due to the predominance of the presence of the glauconite that compounds it and the fossil accumulation of foraminifera (Koesomadinata and Matasak, 1981). The Ombilin formation has a thickness of 1442 m (Koesomadinata and Matasak, 1981), whereas based on Koning (1985), it has a thickness of 2740 meters based on seismic data (Figure 3).

METHODS AND MATERIAL

The research method used is literature study from previous researchers, both published and unpublished to collect information on geological conditions of the research area. Followed by field observation in the form of geological mapping to see and get geological data on the research area and perform stratigraphic crosssection measurements on each research object. Furthermore, from the data that has been obtained in the field of studio analysis and analysis of laboratory analysis of geochemistry, petrography analysis, reservoir analysis, and granulometry analysis. Laboratory analyzes were conducted to support field data and assist in interpreting the depositional environment, facies and architectural data and their implications for the determination of hydrocarbon potential.

RESULT AND DISCUSSION

Sangkarewang Formation

The Sangkarewang Formation in the study area has two characteristics shalestone is gray calcareous shalestone and brown carbonaceous shale rich in organic matter content (Figure 4). These characteristics become the basis for the division of the lithology unit of the Sangkarewang Formation shalestone unit which is divided into calcareous shale and carbonaceous shale. The different characteristics of the calcareous and carbonaceous shalestone are indicated as the implications of different environmental conditions of depositional when the process of depositional the shalestone unit continue.

Characteristic shalestone unit of Sangkarewang Formation indicates that the lacustrine environment in the research area is divided into oxic and anoxic facies when suspension material deposition process continue (Figure 4). The oxic facies deposits the suspension material that forms the carbonaceous shalestone. The carcarous shale properties of the carbonaceous shalestone are interpreted to be sourced from the dissolution of the limestone conglomerate fragments. In carbonaceous shale outcrops found debris flow deposits with thick geometry and composed by grain sized materials to cobble. This indicates that the oxic zone in
the lacustrine environment is relatively close to the surface and includes the lacustrine slope which is part of the deposited material flow debris. Thus, the interfingering facies formed in the oxic zone are characterized by a Brani Formation Tongue composed of pebble to cobble sized crystalline limestone material located between the carbonaceous shale of the Sangkarewang Formation.

Anoxic zones are interpreted to include lacustrine depocentre where suspended material deposits form carbonaceous shale with dark brown characteristics and very low levels of carbonate content. Anoxic zone under the thermocline line has low oxygen content due to density stratification which makes oxygen difficult to circulate into anoxic zones (Nichols, 1999), consequently relatively high CO₂ content. When carbonaceous material enters the anoxic zone, there will be a chemical reaction between carbonate (CaCO₃), carbon dioxide (CO₂) and lacustrine (H₂O) water which produces bicarbonate acid (H₂ (CO₃)₂). With the presence of bicarbonic acid in the anoxic zone will dissolve the existing carbonate material and will leave residual form of calcium.

Sawahlunto Formation

From the results of the lithostratigraphy data obtained from the stratigraphic cross-sectional measurements, it is shown that the Sawahlunto Formation is deposited in the sedimentation environment of the meander river system with facies of main channel, flood plain and point bar, seen in the model of sedimentary environment and facies (Figure 5). This determination is based on suspension precipitation which almost dominates and is associated with fine sandstone (Figure 6).

The main channel facies characteristic is that there is an erosional contact at the bottom of the layer prior to deposited sandstone as the characteristic of the facies, this is influenced by the strong flow rate of the river (bedload). Lithologi composers in this facies is the deposits coarse fractions of medium to fines sandstone with a structure of sediment cross bedding and parallel laminate. The characteristics of overbank facies have a lithologi composition of suspension deposits in form of claystone, siltstone, shalestone and there is a fine sandstone intercalation. Point bar facies has characteristic that is the existence of claystone and sandstone that have sediment structure in the form of parallel lamination. The overbank facies accumulate in the flood plain area with the characteristics of the sediment deposits formed by the fine fraction (Figure 7).
The architecture of the Sawahlunto Formation consists of a sand bed form architecture having a laminate parallel sedimentary structure. The underlying of the sandbars forms the sharp against the bottom of the deposits with finer grains. In general the thickness of the sand bed forms is 4.5-5.5 m. Sand bed forms record intra-channel depositional and possibly produced by migrating dunes within the channel. Furthermore there is an overbank fines architecture, consisting of massive lithology and has fine grain sizes such as clay and shale. The fine material contained in this section indicates fining upward succession. Overbank fines indicate a change of current from strong currents into weaker currents where the coarse grained will settle at the bottom according to the mass of the existing rocks and also the fine grained will settle at the very top because of the small density of the species and makes the fine grained deposited (Figure 7).

The results of the granulometry analysis on the Sawahlunto Formation at the bottom of the stratigraphic measurements show the mean values of 5.92, the standard deviation of 1.6, kurtosis 0.74, and skewness 1.02. Subsequent data at the middle showed a mean of 5.9, standard deviation 1.8, kurtosis 0.87, and skewness 1.04. The upper part shows a mean value of 2.46, standard deviation 1.8, kurtosis 0.85, and skewness 1.05. Granulometric analysis performed on each part of Sawahlunto Formation generally yields a probability curve showing the sedimentation mechanism in the form of saltation. The results of the statistical calculations in each section of the formation also generally result in the standard deviation (SD) values tend to have relatively poor disaggregated grains, the kurtotic values indicate the mesokurtic conditions, and the skewness value yields very positive to positive data, so that predominantly the lithology is sedimented in the form of fine-grained lithology (Figure 8). The results of this analysis prove that the sedimentation facies in the Sawahlunto Formation are facies deposited on the meander environment.

**Sawahtambang Formation**

Based on lithostratigraphy data that characterize the texture of lithology of Sawahtambang Formation, the deposition environment condition of the formation shows the most dominant facies channel. In determining the type facies consider the condition of lithology that changes vertically. In the Sawahtambang Formation of channel development has a change in grain size from old to young with coarse fractions and has a fining upward sequence deposition pattern (Figure 9).
In addition, the Sawahtambang Formation sandstone condition has the development of a crossbedding structure as well as at the bottom of the channel an erosional contact shows that the sedimentation pattern takes place with a strong river velocity. Thus, the stratigraphic relationship of Sawahtambang Formation in the study area has a special characteristic, which is dominated by medium to rough grain sandstones with large layer thickness (Figure 10).

Sawahtambang Formation has a channel architecture characterized by lithology with the size of coarse sand, conglomerate with cross bedding sediment structure. Erosion contained in channel deposits have an erosion or the presence of channels erosion (Fernando et al., 2017). In general, the thickness in the formation of this channel 2-5 m, but some have a channel with a thickness of 4-12 m. Interpreted precipitated with strong energy, low sinosity and in fluvial environments (Fernando et al., 2017). The architecture of the sand bed form has a laminate parallel sedimentary structure, the underlying of the sandstone is the sharp against the bottom of the deposits with fine sand grains. The general thickness of the sandstone bed forms is 2-4 m, although some sandstone bed form has a thickness of up to 11 m. Sandstone forms record intra-channel depositional and possibly produced by migrating dunes within the channel. The gravel bars and bed form architecture has a cross bedding sedimentary structure in conglomerate lithologies. The geometry channels usually like lobate or sheet-like (Miall 1996, Oplusti et al., 2005 in Fernando et al., 2017). In general the thickness of the gravel bars and bed forms is 2 m. Gravel bars and bed forms generally erode or scrape the bottom with fine sandstone from gravel bars and bed forms. This is interpreted by a change in the current on the channel in which a substantial current change coarse grained and erodes a fine at the bottom of this deposited (Oplusti et al., 2005 in Fernando et al., 2017) (Figure 11).

Ombilin Formation

Ombilin Formation Composed of carbonaceous shale and there are limestone lens, sandstones, and claystone. The texture of the shale has a gray to blackish color so it characterizes the conditions in the anoxic area. In addition, the shale contained calcite veins (vein) and berekasi with HCL. The condition of the flakes obtained from macrofossil is pelecypoda (Figure 12). In addition, lithologi contain calcareous shalestone with brown to black color combined with claystone intercalation. Based on these conditions it can be assumed that the environment of Brani Formation in the form of marine environment. Ombilin Formation is deposited in the marine environment through suspension current which facies are pro delta, delta front and flat tidal.
PETROLEUM SYSTEM

Source Rock

Formation Sangkarewang as source rock in the research area, this formation is composed by shale rock lithology and deposited on the environment lacustrine. Based on the results of geochemical analysis, the carbonaceous of Sangkarewang Formation showed the total value of organic carbon (TOC) of 3.40 - 5.21%, the S1 value of 1.01 - 2.45 mg / g, and the S2 value of 11.91 - 28.34 mg / g (Amarullah, 2007 in Oktarina, et al., 2017). According to Peters and Cassa (1994), TOC values of 2-4% have very good potential and TOC values> 4% have excellent potentials, so the carbonaceous of Sangkarewang Formation has very good-excellent potential as source rock. Based on the geochemical analysis data, the carbon of Sangkarewang Formation in North Ombilin Basin has fulfilled total organic carbon parameter, organic matter type, and thermal maturity as source rock which produce hydrocarbon. The results of geochemical analysis of Sangkarewang Formation carbonaceous rocks by Amarullah (2007) in Oktarina, et al. (2017) indicates that the carbon rocks of the Sangkarewang Formation have potential as source rock in the Ombilin Basin.

Migration

Hydrocarbons derived from the source rock of sangkarewang formation then occur a primary migration to the reservoir in the form of sandstone Sawahtambang Formation. The process of primary migration through the mechanism of the pores of the Sawahtambang Formation rocks, based on the grain size of these sandstones, is interlocking to provide migration hydrocarbon roads to the reservoir.

Reservoir

Based on the results of petrographic analysis on the three rock samples analyzed (R1, R2, and R3) (Figure 12), it can be seen that the sandstone units have special categorized porosity values as reservoirs (Table 1), in addition, water volume analysis show permeability of the sandstone units are open so that the porosity and permeability of these sandstone units are interconnected and feasible as hydrocarbon reservoirs. The Sawahtambang Formation not only acts as a reservoir in the petroleum system in the ombilin basin, this formation also acts as a hydrocarbon trap
Based on the drilling conducted by PT CALTEX Pacific Indonesia on Sinamar 1 well, it shows that at the top of the Sawahtambang Formation is made up of sandstone lithology which has an average porosity value of 15%, then with deeper data (1520 m) in the middle Sawahtambang Formation, showing the value of porosity which increased to 20%. The results of the cutting data show that at the top of the Sawahtambang Formation found the presence of hydrocarbons (oil and gas), although with a small amount of flow, but in the middle of the Sawahtambang Formation, the amount of flow has increased. This hydrocarbon source comes from lacustrine shale Sangkarewang Formation. Thus it can be seen that the Sawahtambang Formation has potential as a hydrocarbon reservoir in the Ombilin Basin (Koning, 1985). Sawahtambang formations are considered to have better capabilities as reservoirs because they have interconnected rock pores, making it easier to drain the fluid. Based on research conducted by Koning (1985), Sawahtambang Formation has better potential to be reservoir compared with Sawahlunto Formation. Thus it can be concluded that the results of this study correlated with the results of research from previous researchers, although with different research methods.

**Trap**

Trap on petroleum system at Ombilin Basin is Sawahtambang Formation. This is evidenced by the presence of Anticline Kotogadang and Sawahlular Fault that is interpreted as having the potential to act as a trap of geological structure (Figure 13). Hydrocarbons previously undergoing primary migration to the reservoir, then undergo a secondary migration to both traps. In Antiklin Kotogadang, hydrocarbons will accumulate at the peak of the anticline, while in the outer sawahlular crater, the hydrocarbons will be retained and sealed by the permeable zone in the fault plane that has been filled by destructive lithology in the event of a fault. The presence of antiklin kotogadang as this trap has conformity with the drilling conducted by PT. Kaltex in 1983 on anticline sinamar (Koning, 1985). Thus it can be seen that the type of hydrocarbon trap in the formation sawahtambang trap structure with the type of anticline and a small form of fault.

**Seal**

Seal is used to keep hydrocarbon underneath surface. The rock should be impermeable to hold down the hydrocarbon. The Ombilin Formation claystone has a potential seal for keep hydrocarbon from Sawahtambang Formation reservoir sandstone. Based on the lithologi conditions in the Ombilin Formation it is good to be seal, other than that it refers to the
permeability data having a small quantitative value indicating the permeability in the ombilin formation is very low.

CONCLUSION

Shalestone characteristic of Sangkarewang Formation indicate that the lacustrine environment in the research area is divided into oxic and anoxic facies when suspension material deposition process takes place, so this formation is very role as source rock in research area. Sawahlunto Formation is deposited on the depositional environment of meander river with facies of channel, overbank and point bar. This determination is based on suspension deposits that almost dominates and is associated with fine sandstone. then experiencing the primary migration to the reservoir in the form of sandstone units Sawah Tambang Formation. The Formation Sawah Tambang channel development has a change of grain size from old to young with a coarse fraction and has a pattern of deposition fining upward sequence. at the top of the Sawah Tambang Formation is composed of sandstone lithology which has an average porosity value of 15%, then with deeper data (1520 m) in the middle of the Sawah Tambang Formation, indicating a porosity value which has increased to 20%. the next type of hydrocarbon trap in the Formation Sawah Tambang form trap structure with anticline type and a small part of the fault. The Ombilin formation is composed of carbonated rocks and there are limestone gels, sandstones, and claystone. The Ombilin Formation claystone has a potential seal for keep hydrocarbon from Sawah Tambang Formation reservoir sandstone

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REFERENCE


Figure 1. Map of research area based on tectonic conditions on the island of Sumatra

Figure 2. Tectonophysiographic surface of the Ombilin Basin (Noeradi et al., 2005)
Figure 3. Compilation of the Ombilin Basin Stratigraphy (Silitonga and Kastowo, 1973; Koesomadinata and Matasak, 1981; Koning, 1985; Yarmanto and Fletcher, 1993)

Figure 4. Facies model of lacustrine in the research area and The physical appearance of the calcereous and carboaceous shalestone Sangkarewang Formation.
Figure 5. Facies model and depositional environment of meander river in the research area.

Figure 6. Appearance of lithologi features in facies of Sawahlunto Formation of research area, (a) overbank facies, (b) point bar facies, and (c) main channel facies.
Figure 7. Stratigraphy column and architectural of Sawahlunto Formation in the research area.

Figure 8. (A) Arithmetic curve for statistical analysis of standard deviation, kurtosis, and skewness, (B) Probability curve for sedimentation analysis in Sawahlunto Formation.
Figure 9. Stratigraphy column of Sawahtambang Formation
Figure 10. Appearance of the channel in the research area of the Sawahtambang Formation, A) the lower of the stratigraphic column, B) the middle of the stratigraphic column, C) the upper of the stratigraphic column

Figure 11. Architecture Element Analysis on Outcrop of Sawahtambang Formation
Figure 12. The outcrop appearance of the Ombilin Formation in the study area, which characterizes the presence of pro delta, delta front and flat tidal facies.

Figure 13. The result of petrogafi analysis using bludye method to calculate rock porosity value of Sawahtambang Formation, blue color shows rock pore.
Figure 14. Type of trap geological structure, a) Anticline Kotogadang, b) Fault Sawahluar

**TABLE ATTACHMENT**

Table 1. The porosity value and permeability of sandstone formation sandstone units

<table>
<thead>
<tr>
<th>Sample</th>
<th>Porosity (%)</th>
<th>Porosity Category (Koesoemadinata, 1978)</th>
<th>Permeability (mD)</th>
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<tr>
<td>R 01</td>
<td>28.8</td>
<td>Excellent</td>
<td>189</td>
</tr>
<tr>
<td>R 02</td>
<td>29.9</td>
<td>Excellent</td>
<td>204</td>
</tr>
<tr>
<td>R 03</td>
<td>27.5</td>
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<td>183</td>
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