

# Reservoir Quality Assessment Based on the Occurrence of Burial Diagenesis: Sandstone Case Study from Tanjung Formation, Barito Basin, South Kalimantan

(Penilaian Kualitas Reservoir Berdasarkan Proses Terjadinya Diagenesis Burial: Studi Kasus dari Batupasir Formasi Tanjung, Cekungan Barito, Kalimantan Selatan)

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## Abstract

Barito Basin is known as one of hydrocarbon producing basin which is located in the Southeast Kalimantan. One of its prolific reservoir comes from sandstone facies of Tanjung Formation in the Paleo-Oligocene time. The sandstone undergone diagenesis, subsequently after deposition due to burial process. Burial diagenesis promotes further compaction, cementation and alteration which affect the reservoir quality. This study aims to assess the reservoir quality and its sensitivity against the diagenesis products. Research method was carried out by examine the core samples and scrutiny laboratory observation, such as Scanning Electron Microscope (SEM). X-ray Diffraction (XRD), porosity, permeability, grain density measurement and surface gamma-ray. The results show that the amount and type of alteration is vary by depth, age and lithofacies. Sandstones of sublitharenites and litharenites were buried to depths of 848.29 – 849.80 m and contained significant amounts of authigenic grain-coating and pore-lining clay as well as pore-filling zeolite cements. However, the underlying sandstones from 969.19 – 970.14 m depths exhibit less extensive alteration. In the early burial process, the reservoir quality is modified by the formation of secondary dissolution pores and minerals as a result of silicate dissolution during shallow burial diagenesis. The subsequent burial has reduced the pore spaces through mechanical compaction and cementation. This study certainly valuable addition to our understanding about reservoir quality in correspond to the burial diagenesis.

Keywords: Burial; Diagenesis; Reservoir Quality; Sandstone; Zeolite Cement

## Sari

Cekungan Barito dikenal sebagai salah satu cekungan penghasil migas yang terletak di Kalimantan Selatan. Salah satu dari reservoir yang produktif berasal dari fasies batupasir formasi Tanjung pada kala Paleosen-Oligosen. Batupasir tersebut mengalami diagenesis lanjut setelah diendapkan akibat adanya penimbunan atau penumpukan sedimen di atasnya. Diagenesis burial mengakibatkan terjadinya kompaksi lanjut, sementasi dan alterasi yang mempengaruhi perubahan kualitas reservoir. Studi ini bertujuan untuk menilai kualitas reservoir dan sensitivitasnya terhadap produk diagenesis. Metode penelitian dilakukan dengan memeriksa sampel core and melalui observasi detil di laboratorium, yakni Scanning Electron Microscope (SEM). X-ray Diffraction (XRD), porositas permeabilitas, pengukuran densitas butir dan gamma-ray. Hasil penelitian menunjukkan bahwa jumlah dan tipe alterasi yang berlangsung relative bervariasi menurut kedalaman, umur dan litofasiesnya. Batupasir tipe sublitharenit dan litharenit mengalami penimbunan pada kedalaman 848,29 – 849,80 m dan mengandung sejumlah semen lempung autigenik berupa grain-coating dan pore-lining serta semen zeolite. Namun batupasir di bagian bawahnya, yakni pada kedalaman 969,19–970,14 m hanya mengalami sedikit perubahan. Pada awal proses penimbunan, pelarutan dari mineral silikat yang berlangsung pada kedaaman dangkal menyebabkan terjadinya pembentukan porositas dan mineral sekunder yang memodifikasi volume ruang pori. Pada tahap penimbunan lebih lanjut, ruang pori ini menurun akibat terjadinya kompaksi mekanik dan sementasi lanjut. Studi ini tentunya memiliki nilai penting untuk memahami tentang kualitas reservoir terhadap proses diagenesa burial.

Kata-kata kunci: Penimbunan; Diagenesa; Kualitas Reservoir; Batupasir; Semen Zeolit

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## I. INTRODUCTION

Assessment of the reservoir properties (such as porosity and permeability) is equally important for hydrocarbon reservoirs. Reservoir properties have been recognized as the consequence of sedimentary structure and texture that initially present during

deposition, this is subsequently affected by diagenetic events which take place during the post-depositional change. In general, there is a strong relationship of the burial history with diagenetic events, in which the intensity of diagenetic events normally in correspond to the increasing of burial

depth and age. However, the Paleo-Oligocene sandstones of Tanjung Formation, Barito Basin show anomaly of the diagenetic events toward the depth of burial. To reveal, detailed observation of the sequence stratigraphy should also be carried out to identify the depositional sequence bounding unconformities and the maximum flooding surface. Tectonic uplift and deformed regions that experienced high geothermal gradients contribute to the variety of rock modifications with regards to diagenesis [1]. Meanwhile, depositional sequence may define the amount and rate of fluid that flowing through pore – throat [2]. The fluid flow has been important to increase diagenetic process. Compaction, early dissolution and secondary porosity development have important implications for the study of non-marine sandstones in a greater depth [3]. However, dissolution processes able to distort provenance, tectonic setting, and depositional environment interpretations based on the detrital mineralogy of the older sediments [4]. Referring to the findings above, despite tectonic deformation modify the rock properties by providing either connectivity or fluid entrapment, depositional sequence ultimately drives the diagenesis. This research is done by examining the fundamental controls of diagenetic events (including compaction, dissolution, cementation and grain replacement) on reservoir properties (porosity and permeability). This study illustrates an additional information of the reservoir characterization in order to assess reservoir quality, sensitivity and its influence factor.

## II. MATERIALS AND METHODS

### 2.1 Materials

Sandstone samples were collected from a series of siliciclastic conventional core samples from 4 depth intervals of 842.00 - 852.00 meter core #1 (Layer D), 883.00 – 891.50 meter core#2 (Layer C), 962.00 – 973.0 meter core # 3 (Layer B) and 1035.00 – 1044.00 meter core # 4 (layer A) taken from Tanjung well, South Kalimantan, Indonesia. Seventeen core plug samples had been taken from those 4 different layers.

### 2.2 Methods

Various laboratory examinations include detailed core description (core logging), thin section petrography, Scanning Electron Microscope (SEM) and X-ray diffraction (XRD). Routine core analysis is used to identify the porosity, permeability, grain density measurement and surface gamma-ray. Detail standart methods for each analysis are described as below :

Core description is a combination of detailed megascopic (visual) and scanned core description to identify the lithological features and facies sequence.

Thin sections were prepared from the horizontal

core plug samples that has been sliced 2 cm in thickness and impregnated with blue-dyed epoxy resin to maintain the existing natural porosities of the rock samples and to recognize porosity under polarization microscope [5]. Petrographic point-counting analysis (400 grains) of the thin section was carried out to quantitatively determined the grains composition (both primary and secondary origins) and visual porosity percentages.

Preparation for SEM analysis comprises of coated samples with both carbon and gold alloy and then examined in a JEOL JSM-6390LA SEM. SEM analysis was conducted to examine the geometry of the pore systems and to determine the type and distribution of sensitive minerals, especially for understanding the growth of authigenic minerals pattern such as clays and silica cements within pore systems.

XRD analysis was performed on rock samples to quantitatively determine the whole rock and clay mineral content in terms of weight percent composition of the whole rock. Clay mineral analysis involved ultrasonic disaggregation and centrifugation to isolate the clay fraction (< 4 microns), followed by the preparation of oriented clay mounts that were run in untreated, glycolated and heated (360°C) [6].

## III. REGIONAL GEOLOGY AND STRATIGRAPHY

### 3.1 Regional Geology

Barito basin is located along the southeast margin of Shield Schwaner in South Kalimantan. This basin has developed after the collision of Paternoster and SW Borneo micro-continents [7]. Currently, the basin is characterized by the complex structural pattern in the northeast of the basin, as denoted by the narrow parallel folds trending northeast, bounded by Meratus mountain. The existences of a large fault rotation were marked by a reversed pull or fold and fault lines. Unique structures in the NE basin were interpreted as a consequence of tectonic half-siege in the area by two major events in the pre-Tertiary [8]. Western and southern Barito Basin have a slight tectonic and showed almost no structural deformation. Thin layered tectonic events are characterized by undistinct anticline in this basin.

### 3.2 Stratigraphy

The regional stratigraphy of the Barito Basin can be divided into three groups (Fig. 1), they are pre-Tertiary (basement), Tertiary (Tanjung to Dabor Formation) and Quaternary [9]. The intended formation for this study area is Tanjung Formation (Eocene-Paleocene) which has been deposited unconformably in the Pre- Tertiary basement. Tanjung Formation was deposited in a fluvial to shallow marine environment; the thickness of this

formation reaches 750 m. The outcrop of the Tanjung Formation extensively exposed in the north of the basin and in the east of the west flank of the Meratus mountain. In lithostratigraphic, the Tanjung Formation was split into bottom, middle, top, and member of the claystone. Bottom of the Tanjung Formation consists of the interbedding coarse-grained sandstone, conglomeratic sandstone, and conglomerate, with a thickness ranging from 20-50 cm [10, 11]. Furthermore, the middle is dominated by the gray claystone with coal seam intercalation, and local sandstone intercalation. Gray to locally black claystone is composed of thin intercalation of fine gray sandstone (thickness of about 1-3cm). Sandstone intercalation is coarse-grained, light gray color and has cross bedded structures. The top of the Tanjung Formation is dominated by thin interbedded of siltstone and fine sandstone with wavy and lenticular bedding, as well as flaser structures. In addition, fine-grained sandstone is found as thin layer intercalation, with thickness of about 2 to 5 cm.

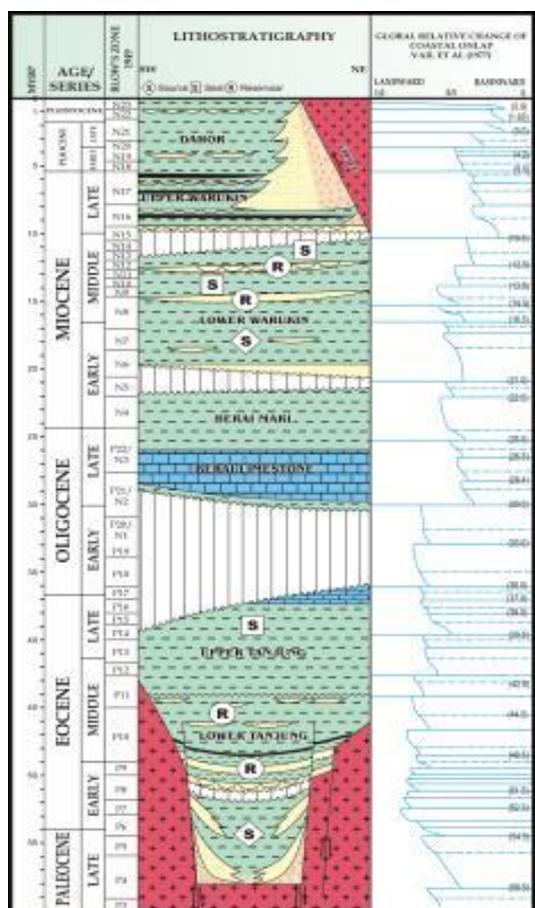


Figure 1. Regional stratigraphy of Tanjung Formation, Barito Basin (Sapiie, B., et al., 2004).

#### IV. DEPOSITIONAL FACIES

The Paleo-Oligocene sequence of sandstone from Tanjung Formation, Barito Basin, Indonesia eISSN: 2614-0268

consists of 14 facies sequences namely facies A to N and within this sequences there are 4 sand layers. Most of sandstone comprises of sub- litharenite and litharenite (predominated by volcanic rock fragment). Core description led to the identification of 4 layer (such as A, B, C, D from bottom to top). Layer A (Fig. 2) shows prograding highstand stage of estuarine delta system and can be differentiated into 3 facies including facies A (thickening upwards of coarse clean sandstone), facies B (thickening upwards sandstone with rare pebble fragments) and facies C (thickening upwards of coarse sandstone with intercalation of conglomerate). The top of facies C is interpreted as sequence boundary (SB) and as a product of LST of fluvial channel in estuarine delta system. Sandstone of facies A (depth of 1036.25 m) and B (1038.34 – 1042.43 m) have a typical of volcanoclastic and has been determined as litharenite. Petrographically, sandstones from facies A to C have grain size ranges from medium to coarse, well sorted and sub rounded to rounded in shapes. Reservoir quality indicates poor to moderate.

Layer B overlains the layer A and has 3 facies (Fig. 3), consist of facies D (pebbly granule conglomerate), facies E (fining upward of medium to fine clean sandstone) and facies F (massive to friable shales). Sandstone of facies D (depth of 972.28 – 971.25 m) and E (969.19 – 970.14 m) have a typical of volcanoclastic and belong to litharenite. Sandstone has medium to coarse grained in size, well sorted and subrounded to rounded in shapes. Volcanic sandstone (litharenite) produces a high gamma- ray response. Dissolution mainly happens toward feldspar and volcanic rock fragments. The presence of conglomerate facies indicates that those facies were deposited under high energy condition of fluvial channel in estuarine delta system. The presence of carbonate layer in facies F, which was developed on the top of the facies, presents as a flooding surface, whereas Maximum Flooding Surface is evidenced by the enrichment of pelagic.

Layer C (Fig. 4) is divided into 4 facies includes facies G (poorly sorted conglomerate), exhibits fluvial deposits as controlled by high energy condition [11], facies H (fining upward of medium to fine clean sandstone), facies I (fining upward of fine sandstone with shale intercalation) and facies J (interbedded of very fine sandstones and shales). Sandstones of facies H (depth of 887.25 – 889.17 m) and I (885.33 – 886.79 m) are determined as sub-litharenite. Sandstone has fine to medium sand sized, moderately to well sorted and subrounded to rounded in shapes. Reservoir quality is generally very good, except for facies I which has poor to moderate reservoir quality.

Layer D (Fig. 5) was divided into 4 facies include facies K (massive shale), facies L (fining upward of very coarse to fine sandstone), facies M (fining

upward of fine to very fine sandstone) and facies N (massive shale that slightly oxidized). Sandstone of facies L (depth of 848.29 – 849.80 m) is determined as sub-litharenite. Sandstone has medium to coarse grained in size, well sorted and sub-angular to rounded in shapes. Reservoir quality is generally moderate to good, especially in facies L. Textural condition, particularly grain size, roundness and

grain- sorting contributes to the quality of facies L. Most of the facies of layer C and D shows a succession of transgressive phase period. Depositional sequence from each sedimentological logs indicating a stacking of the sediment deposition in transitional environment (particularly along the paleoenvironment of fluvial to marine. depositional sequence model for all layers is illustrated in Fig. 6.

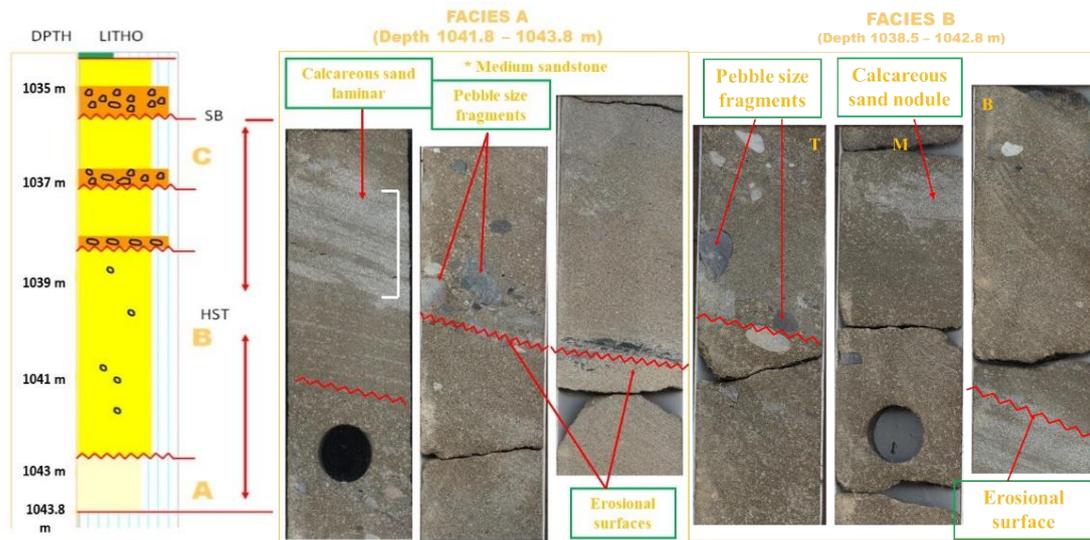


Figure 2. Sedimentological log and facies sequence of Layer A, consists of facies A, B and C. Core data exhibits blocky sandstone.

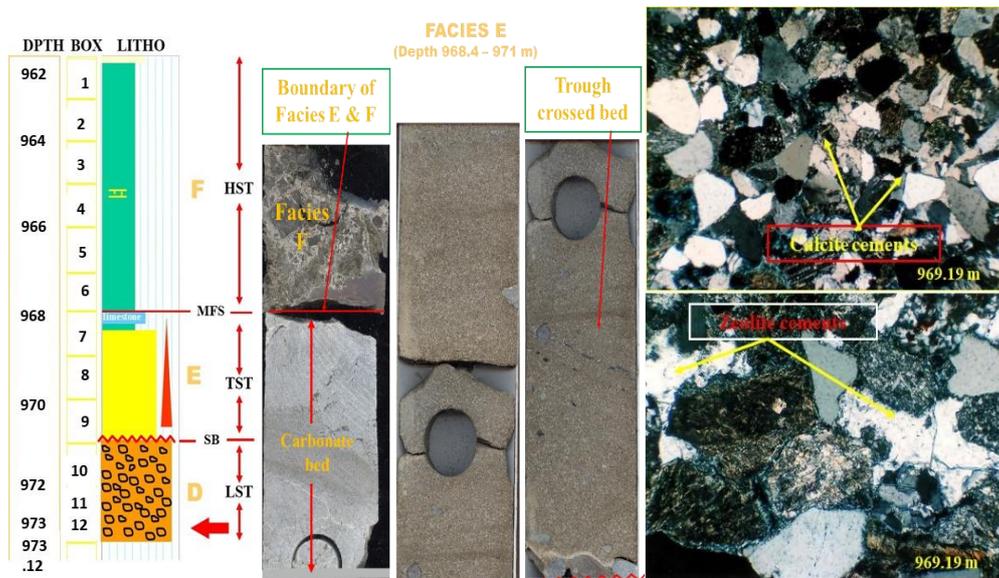


Figure 3. Sedimentological log and facies sequence of Layer B, consists of facies D, E, F. Core exhibits fining/ thickening-upward, transgressive succession. Right figures show photomicrograph of sandstone in facies E that is commonly cemented by blocky calcite and zeolite.

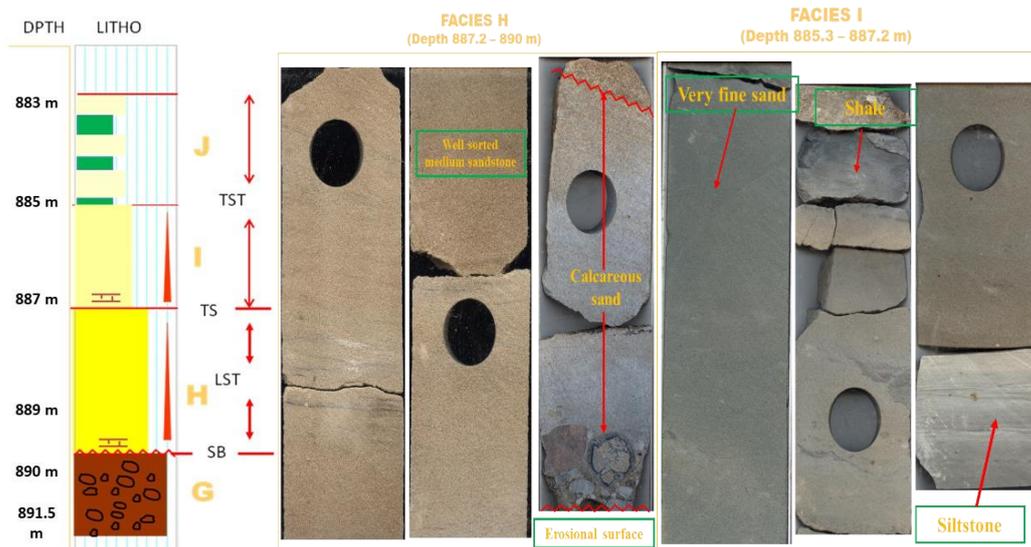


Figure 4. Sedimentological log and facies sequence of Layer C, consists of facies G, H, I, J. Core from Tanjung well sand shows fining-upward, transgressive succession. Abundant burrows are found in the facies J.

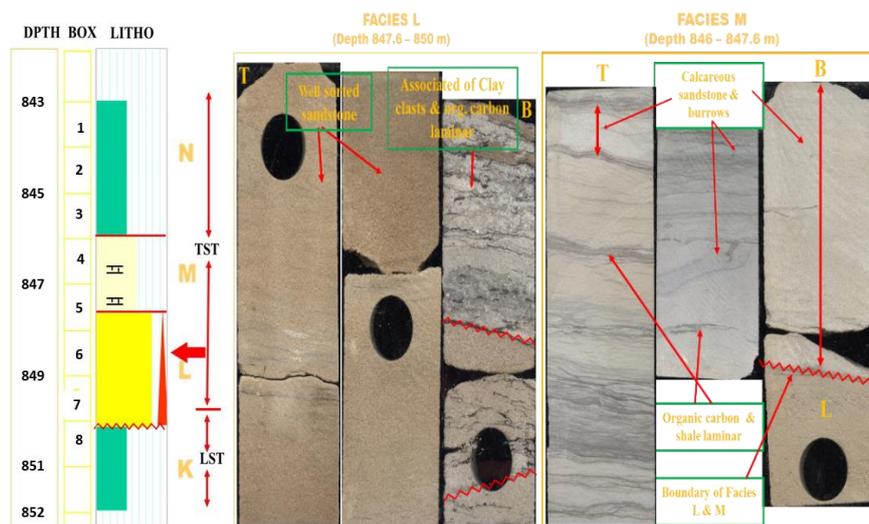


Figure 5. Sedimentological log and facies sequence of Layer D, consists of facies K, L, M, N. Core data exhibits fining/thickening-upward, transgressive succession.

## V. SAND QUALITIES

Quartz, feldspar and lithic grains dominate the mineralogy composition of most sandstone. Other minerals, such as carbonaceous material, micas, heavy and opaque minerals present in minor proportion. Sublitharenite is predominantly composed of the altered lithic sediment and metamorphic, whereas litharenite mostly have moderate proportion of lithic volcanic (15-20%) and additional pyroxene mineral. Additional pseudomatrix exists as produced from decayed rock fragments and other unstable grains which is squeezed due to progressive mechanical compaction. Depositional controls, such as diverse grain size and matrix content has reduced the

effective porosity. The sandstones mostly shows well sorted. Based on petrography and routine core analysis, sandstones show a variety of pore and permeability value with typical pores of primary intragranular and secondary dissolution. Dissolution of plagioclase and volcanic rock fragments has occurred in nearly all samples, dissolving up to half of the framework grains and increasing the visual porosity [1].

## VI. DIAGENETIC EVENTS

Sandstones were silica cemented in two major phases – an early and late-stage massive cementation of quartz overgrowth. The main diagenetic phases recorded are: quartz overgrowth,

kaolinite, chlorite, illite with minor dolomite. Calcite and pyrite occur as additional authigenic minerals.

With-depth alteration of the various components

result in the successive stages of silica-release. Released silica was partly used for the precipitation of smectite and zeolite (Fig. 7). At deeper depth, At deeper depth, smectite [12].

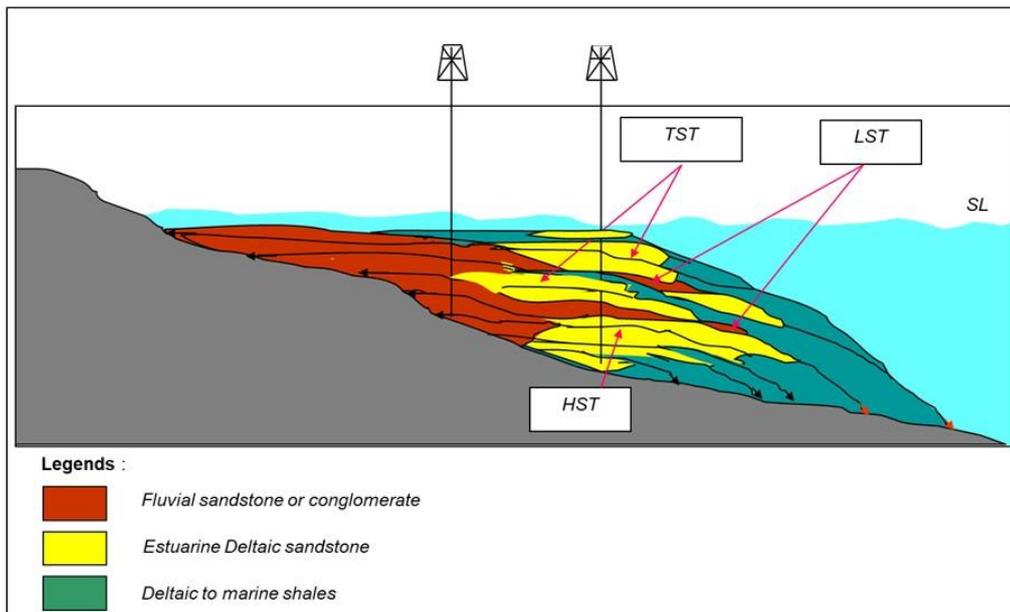


Figure 6. Depositional sequence illustration of the studied facies reconstruct based on several sedimentological log

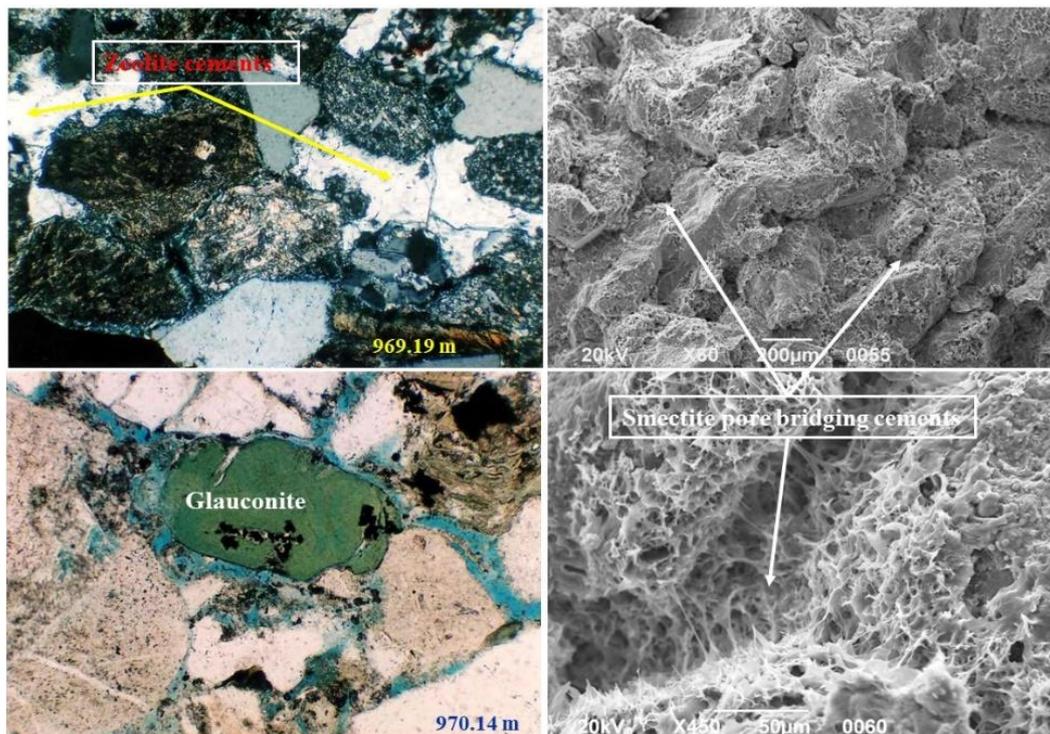


Figure 7. Photomicrograph of petrography (left) and SEM analysis (right) for litharenite (Facies E, Layer B) shows pore-blocking zeolite cement and pore-bridging of smectite. The occurrence of glauconite indicates deposition takes places in relatively shallow marine.

The smectite to chlorite transformation released silica at the expense of iron [13]. Many studies have shown a significant transformation of smectite to illite with depth. The transformation contributes to the major silica source for quartz cement. Potassium feldspar is less recorded at the shallowest depth. It is suggested that the lack of diluted potassium sources has delayed the smectite transformation. The major silica mobilization occurred at shallow depths, related to the transformation of volcanic ash, and at intermediate depths, related to the dissolution of zeolite. At these processes, the shale facies may have been an active silica exported. Sandstone cementation indicates that the earlier phase is related to the major precipitation of silica. This massive quartz cementation contributes to the pore volume reduction in a shallow depth, however the late stage of smectite to chlorite transformation inhibit the quartz cement growth [14].

Altered volcanic rock fragment in litharenite samples are mostly have authigenic smectite and

zeolite, but most samples have a minor detrital component of illite. Laumontite and clinoptillolite occur as coarse crystal (0.01-0.2mm) of zeolite cement in the volcanic sandstone of the Tanjung Formation. Laumontite is mostly found as blocky shaped crystal, whereas clinoptillolite mostly found as coffin-shaped crystals or crystal aggregates within intergranular pore spaces. Zeolite cement occurs locally as remnants in the calcite-cemented sandstone, which implies an early formation of the zeolite [15]. Zeolite usually does not accompany smectite, but if smectite is present, it occurs as a late coating on the zeolite. Zeolite cement is mainly plug sandstone samples from the intermediate depth. The heterogeneity of diagenetic events has the main effect toward the reservoir properties (Fig. 8).

Under normal condition, porosity and permeability reduced through depth of burial. However, variety and level of diagenesis play contributes to the development of porosity and permeability.

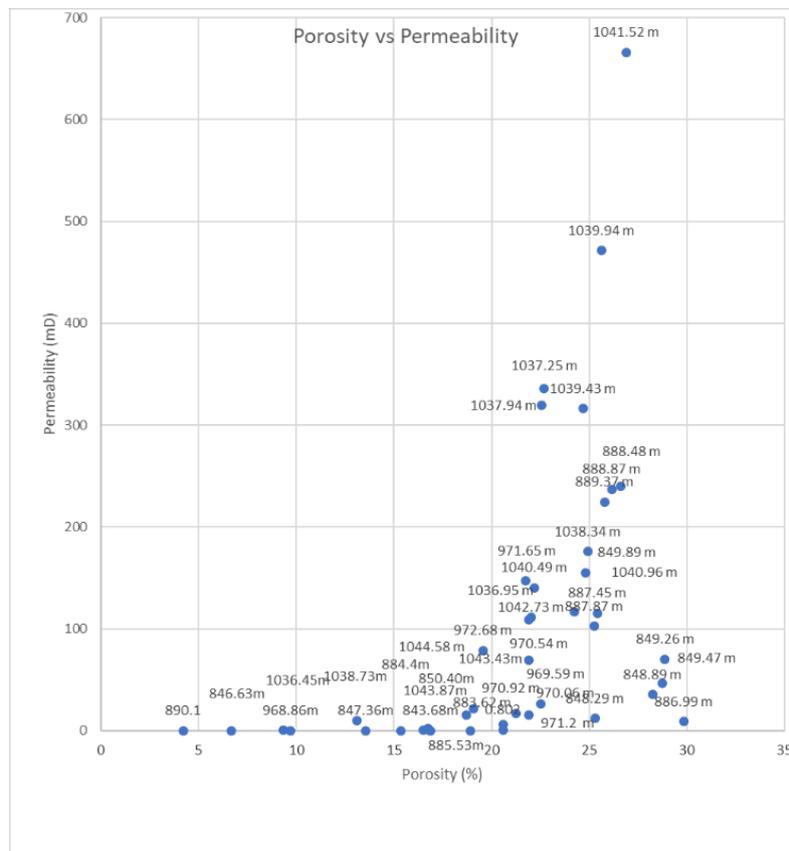


Figure 8. Reservoir properties vary through depth as indicated by the crossplot of porosity against permeability

## VII. RESERVOIR SENSITIVITY

According to the existing of authigenic minerals such as kaolinite, chlorite, illite, quartz overgrowth, zeolite, pyrite, dolomite and calcite within the

studied cores, at least three main engineering problems may occur.

First, migration of fines particularly in second group (Layers C and D) is caused by the high content of kaolinite booklets with subordinate chlorite and

illite (Fig. 9). Authigenic kaolinite usually occurs in a series of booklet hexagonal plate forms commonly loosely bound from pore-walls. The kaolinite crystals are easy dislodged and migrated under high fluid turbulence condition and contact with freshwater based fluids or high pH fluids (higher from 10) [16]. This lead to an abnormal decline in the early production history of the well.

Second, iron-hydroxide and calcium fluoride gel precipitates. Almost all studied sandstones are sensitive upon acids, especially HCl and HF due to their iron-bearing mineral and Ca-bearing minerals contents (zeolite and calcite cements, Fig. 7). The use of HCl and HF at the completion well will promote to the precipitation of gelatinous iron hydroxide in permeability reduction near the well bore [17].

Three, swelling problem is potentially happened in the first group of rocks that related to the sandstone facies with significant content of

authigenic smectite as diagenetic product. XRD examination shows smectite present in the range 1.00 % - 14.00%. In regards to water flooding project, the type of water that will be injected into reservoir should be carefully selected and avoid using fresh water system [16, 17].

Other problems may appear in the log response such as gamma-ray, resistivity and density logs. In regards to the influence on gamma ray reading, it can be identified in the first group (Layers C and D), where their interval has high content of both single crystal K-feldspar and plagioclase or Feldspar within volcanic rock fragments that could affected the gamma ray response. The surface gamma-ray measurements in Layers C and D, especially for conglomerate and sandstone facies indicates the high GR values (Facies B and Facies C at core #3; Facies D at core #2). This matter could lead to the lithology miss-interpretation.

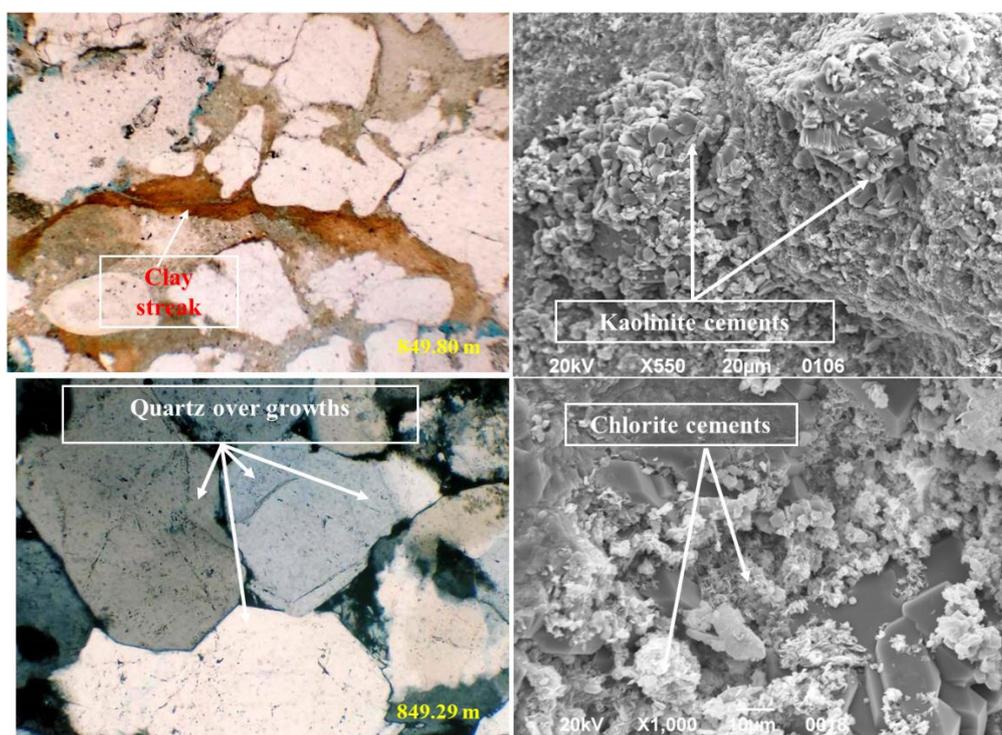


Figure 9. Photomicrograph of facies L shows the mode of occurrence of abundant kaolinite and chlorite occurred as grain coating and pore-lining cements in sublitharenite. These clay cements are effectively inhibit the late growth of quartz cements.

## VIII. CONCLUSIONS

1. Porosity and permeability varies in all sandstone samples, this is mainly affected by initial depositional facies and the intensity of diagenesis from respective depth.
2. Intensity of diagenesis (e.g. cementation and replacement) is particularly affected by the depth of burial, age and relative to the stratigraphic sequence position.

3. Early quartz cementation may strengthen grains from further compaction. Clay cements have grown as a combination of grain-coating, pore-lining and pore throat-blocking clots, whereas zeolite mostly grown as pore-blocking cement.

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