Reservoir Characteristic of Triassic Sandstone, Eastern Seram, Maluku, Indonesia

Akhmad Khahlil Gibran¹,³, Aries Kusworo², Joko Wahyudiono², Huzaely Latief Sunan¹, Deventi Nur Aeni¹ and Afif Alghazali¹

¹Geological Engineering Department, Universitas Jenderal Soedirman, Jawa Tengah, Indonesia
² Geological Survey Center, Geological Agency, Ministry of Energy and Mineral Resources, Indonesia
³akgibran@unsoed.ac.id

Abstract. The Triassic aged sandstone from Kanikeh Formation, are spread across Seram, Kesui and Teor Island. The Kanikeh formation has been known as excellent source rock, however, reservoir characteristics of this formation are unknown. This paper aimed at the diagenetic influence on reservoir characteristics was investigated for the Carnian-Norian sandstone sequence in the Eastern Seram. This study comprises two methods which are petrographic analysis and Scanning Electron Microscope-Energy Dispersive Spectrometer (SEM-EDS). The petrographic analysis shows the sandstones of the Carnian sequence in the Eastern Seram are lithic wacke, litharenite, arkose. SEM-EDS observations showed that the minerals belong to the silica group derived from the silica minerals, feldspar, clay, and mica minerals. The silica mineral is a quartz grain. The observed feldspar mineral is K-Feldspar in the form of granules. The most dominant clay minerals are smectite, illite, chlorite, kaolinite, halloysite. The observed mica group is muscovite. Diagenetic identified in these sandstones include compaction, cementation by calcite, quartz, clay minerals, iron oxides, dissolution, and alteration of unstable clastic grains, tectonically induced grain fracturing. Unstable clastic grains like feldspars suffered considerable alteration to clay minerals. Based on characteristics of the Diagenetic, the Carnian-Norian sandstones in the study area have a negligible reservoir characteristic.

1. Introduction
In Bula Basin, could be found 2 active oil and gas blocks, which are Bula Block with sandstones and limestone play aged Quaternary and Oseil Block with limestone play aged Triassic-Jurassic. Based on biomarker analysis, the oil from Bula and Oseil Field come from the same sources[1]. Kanikeh Formation has been known for the long term and has a good characteristic for main source rock[2][3][4]. Carnian-Norian sandstones in Kanikeh Formation could be indicated has a good reservoir[4]. Kanikeh Formation is the oldest sediment that could be found in Bula Basin[5]. This formation arranged by siliciclastic rocks that pressed unconformity by the oldest metamorphic rocks and could be found fault contact with the other oldest rock[6]. Kanikeh Formation consists of the repetition of sandstone and shale which spread across Seram Island to Kesui Island and Teor in Southeast Maluku[7][8].

Study of Kanikeh Formation sequence had been chosen due to a wide resource in Maluku (figure 1) and the newest discovery for oil sources that comes out from Mesozoic rock in the Bula Basin of sediment, likewise in the research area. The aim of the study in Kanikeh Formation clastic sequence is to reveal the diagenetic history with reservoir characteristics using a surface sample as analog
subsurface for understanding the reservoir quality using an approach of petrography and Scanning Electron Microscope-Energy Dispersive Spectrometer (SEM-EDS). The research area is by passed by many faults that cut the basement with direction north west-south east and elongated to eastern of Papua Island[9]. The structure along Seram Island represented as a sinistral and dextral strike-slip fault[9] (figure 2). The folds that grow with strong deformation and associated with every rupture in different directions. A fold formed asymmetric anticline that dipping two directions and could be found in the field.

**Figure 1.** Geology map of Seram Island (Hill,2012). A red box is the research Area, (1) Lofin observation, (2) Niner observation, (3) Oseil observation and (4) Bula observation

**Figure 2.** Tectonic setting of East Indonesia, showing that Tarera Aiduna Fault that becomes one of the structures that controlling the development of structural geology in Seram Island[9].

2. Methodology

The method that we use for collecting the stratigraphy sample and data is using the stratigraphy measuring section. The stratigraphy measuring section have been done in Bula, Oseil, Niner, and Lofin area. The literature review is our first stage for the research, which include a literature review that has been published. It used for understanding the major interpretation of geology condition of the area, the location of outcrop observation, and knowing the major issue in these formation, which shows the diageneric process that affect the reservoir quality. Geology map and to topography map analysis in this research area have been done before fieldwork. After doing the literature review, we do the preliminary survey for knowing the main road access and outcrop condition which could be indicated as our first research target. The map of the geology track that has been chosen is road, river, and cliffs to get a good outcrop. The major data collected include the stratigraphy measuring section, rocks sample, and documentation.

26 samples are used for representing the study of Petrography and SEM-EDS. Major description and Autogenic Mineral from Sandstones based on the 26 samples consist of Petrography samples and SEM-EDS. The result of these petrography laboratory work is a thin section of rocks that produced by Basic Geology Laboratory, Centre For Geological Syuey Bandung. Research under polarization microscope in Petrography Laboratory, Centre For Geological Syuey by a researcher to know the mineral composition of rocks, type, and the diageneric from each rock. The purpose of SEM analysis to observe the morphology, and rock composition or mineral. Morphology to analyzed shape and dimension from the sample; Composition to analyzed a composition from surface quantitatively and qualitatively. Preparation and testing of the SEM sample have been done in Basic Geology Laboratory, Centre For Geological Syuey, Bandung. The testing is using Scanning Electron Microscope JEOL JSM-6360LA, complete with Energy Dispersive Spectrometer (EDS) system JEOL.
JED-2300, and could enlarge the object up to 300,000 times and determine the concentration of chemical elements semi-quantitatively.

Diagenetic is a physics, chemical, and biological process which turns sediment into sediment rocks. As a result, mineralogy and/or texture become different\cite{10}. Diagenetic occurred after the deposit to metamorphosis (high temperature until 150°/200°c with/without pressure). Diagenetic occurred where mineralogy of rocks in unstable conditions as the result of transformation in physics, chemical, or biological conditions. The unstable mineralogy usually occurred in grains contact and pores between grains. A change of pressure and temperature causing a new mineral formed or the existing mineral before occurred a change, adjusting on new equilibrium. There are a few diagenesis classifications that could be used for knowing the grade of sandstones diagenetic\cite{11}\cite{12}\cite{13}\cite{14}.

The diagenetic process based on the burial effect to early shallow subsurface becomes Group A, late deep subsurface as Group B and Group C\cite{12}. The diagenesis stage becomes eodiagenetic, an immature mesodiagenetic, semi-mature mesodiagenetic, mesodiagenetic mature A, mesodiagenetic mature B, and super mature\cite{11}. The diagenetic stage becomes stage Ia, I, II, III, dan IV\cite{14}.

3. Field Study
Outcrop Observation and collecting the sample could be focused on siliciclastic rocks aged Triassic, in this case, sediment rocks that placed in Kanikeh Formation. All of the samples collected based on stratigraphy sequence and geographic location (Figure 1).

4. Results
4.1. Petrography analysis
The purpose of petrography analysis toward 5 samples of siliciclastic rocks such as sandstone of Kanikeh Formation have been done by doing some microscopic analysis to observe the mineral composition (Table 1), texture, and diagenetic stages that occurred in these rocks. Based on the presentation of mineral composition (Quartz (Q), Feldspar (F), Lithic (L)), and the representation of the matrix amount, a rock could be classified into sediment classification\cite{13} (Figure 3).

The number of presentations calculate in every type of mineral and determines the name of rocks show in the Petrography Classification of Siliciclastic Rock (Figure 3). The result of 3 type are Lithic Wacke, Arkose, and Litharenit.
### Figure 3. Classification of petrography for siliciclastic in Kanikeh Formation in the research area\(^{[13]}\).

### Table 1. Composition of all the rocks based on petrography analysis.

| Sample Code | Fragment | Cement | Replacement | Porosity |
|-------------|----------|--------|-------------|----------|
|             | Monocrystalline Quartz | Polycrystalline Quartz | Total Quartz | Feldspar | Lithic | Mica | Carbon | Opale | Matrix | Clay | Carbonate | Oxide | Recrystallization of calcite | Chlorite | Recrystallization of matrix | Intragranular | Intragranular | Total | Rock Type of Pettijohn (1987) |
| 14KG025     | 20        | 4      | 24         | 7        | 25      | 6     | 2      | 3      | 16     | 10   | 0      | 2     | -      | -       | 5      | -       | 100           | Lithic wacke |
| 14KG037I    | 30        | 12     | 42         | 5        | 10      | 3     | -      | 8      | 19     | 3    | -      | -     | -      | -       | 10     | -       | 100           | Lithic wacke |
| 14GO44C     | 20        | 10     | 30         | 5        | 7       | 3     | 8      | 5      | 20     | 14   | -      | 5     | -      | -       | 3      | -       | 100           | Lithic wacke |
| 14GO45R     | 20        | 10     | 30         | 12       | 5       | 3     | 5      | 4      | 4      | 10   | -      | 2     | 2      | 5       | 2      | 5       | 100           | Arkose      |
| 14KW20C     | 18        | 7      | 25         | 5        | 7       | 4     | 5      | 3      | 11     | 5    | 20     | 3     | 2      | -       | 7      | 3       | 100           | Litharenite |

### Figure 4. A. Position for plane light; B. Position for cross-polarized light. A thin-section of arenit felspathic, has a good-sorted, grain relation generally long contact, embedded and suture contact, cementation system are iron oxide, matrix recrystallization, and calcite, replacement is an opaque mineral, calcite, and chlorite, pore system is channel and intragranular.

#### 4.2. SEM-EDS analysis

The purpose of SEM-EDS analysis toward 21 samples of rocks it which collected from 4 different field study and type of lithology consist of sandstone and claystone is to observe the topography, morphology, and rock or mineral composition.
SEM-EDS observation that have been done and could be indicated in the silica group that comes from silica, feldspar, clay, and mica mineral group. The silica group consists of quartz grains, feldspar group that observed is K-feldspar such as grains (figure 5). The most dominant clay mineral group appears between smectite, illite, chlorite, kaolinite, halloysite, and mica group that observed is muscovite.

![Figure 5](image)

**Figure 5.** KW23L sample under SEM shows quartz grains (Q) and pores of rock (P) that surround by illite mineral (yellow arrows) and chromatogram showing the spectrum of major elements such as C, Mg, Al, Si, K, Fe.

4.3. The quality of rock porosity

The potential of reservoir rock could be determined for the observation result of lithology and the diagenetic process which occurred in it. The detail of petrography analysis from the thin section shows 5 samples of sandstones from kanikeh formation has an immature texture with a subangular shape and poorly-sorted. The appearance of abundant lithic shows as immature mineralogy. Immature texture, in general, has poor porosity, but has the good permeability, due to the grain shape that angular toward the pores of rock. Characteristic of the reservoir of sandstones depend on the diagenetic process, this process could increase or decrease the rock porosity, the important process is compaction, dissolution, and cementation by calcite, clay mineral and iron oxide.

The process of mechanic compaction that occurred in these 5 samples shows that the rocks getting joint strongly and create the secondary porosity, the secondary porosity consists of many fractures in rocks could be the dissolution media that could increase grade porosity and permeability, but joint that we observe not intensify. Dissolution that occurred for the 5 samples on sandstone shows that the dominant dissolution is feldspar. Dissolution could be occurred near the earth's surface by meteoric water\(^{15}\) or the deeper depth by water that results from diagenetic process from organic material or clay mineral\(^{16}\)[17]. The dissolution process formed the secondary porosity and be a major factor for pore rocks forming.

The cementation process that occurred is cementation by calcite and iron oxide. All of the cementations could decrease the permeability and porosity grade. The process of authigenic mineral forming also observed as clay mineral forming but couldn’t be identified what kind of clay mineral is. The appearance of clay mineral will form discrete-particle pore bridging and pore lining. Forming of discrete-particle formed by kaolinite pore bridging by chlorite mineral and pore-lining by illite. From three kind of formed which comes due to authigenic mineral could decrease the permeability and porosity grade, but discrete particle didn’t affect the permeability rock. The reservoir characteristic
that we get from the research shows the porosity grade around 3%-15%, moreover, it could be classified as denying to enough (porosity classification\(^{[18]}\)) so, the reservoir potential could be denied.

5. Discussion
The sandstone has a various composition of quartz and lithic. Classified into *lithic wacke, arkose, dan litharenit*. The diagenetic process formed sandstones including compaction, cementation, and dissolution. Characteristics of the reservoir could be affected by the sandstone composition, the burial depth, and the uplift massively. The major mineral of diagenetic appears in sandstones, such as calcite, quartz, and iron oxide with a clay mineral. Feldspar has been altered during the diagenetic process and shows form the dissolving and alteration which occurred intensively in clay mineral. Secondary porosity is the result of early and late dissolution, in clastic sandstones, authigenic mineral, and cement. Compaction and cementation of calcite as the main major for decreasing porosity in sandstones. Kaolinite is an authigenic mineral, clay is the most common appear in sandstone, also appear illite and smectite in small occurrence. The porosity is controlled by the compaction and cementation, in this case, the porosity, in general, will be decreased during the compaction and cementation by iron oxide, quartz, calcite, and kaolinite. The secondary porosity formed from the dissolution of feldspar and calcite as the response form burial progressive. The appearance of clay mineral that covered or filled the pores caused decreasing of porosity and permeability. The permeability is caused by the influence of *authentic clays* appearances such as kaolinite, smectite, and illite. Dissolution in calcite cement in a few has a contribution by influencing the amount of secondary porosity. The abundance of authigenic kaolinite also brings the influence towards microporosity. Permeability would be increase by the increase of porosity, but it has weak relation, which means the porosity not give the major contribution towards the permeability grade. The appearance of tiny content and or the difference in the size of pore could be represented as the weak correlation between porosity and permeability. The index of reservoir quality depends on permeability if the permeability getting highest the reservoir quality getting better so in reverse.

The petrography observation shows that Carnian-Norian sandstone has an *immature* texture, based on the number of subangular grains, not compact of grain size has contained so many clay mineral as matrix and contains much of feldspar grain. These conditions caused the porosity grade in Carnian-Norian sandstones poorly (Table 1). Based on compaction process it could be characterized by dominance between long contact grain (Figure 4), concave-convex contact (Figure 4), with a tiny expose of mica, the appearance overgrowth quartz cause pressure solution (Figure 4) and change of smectite clay mineral become illite (Figure 5), with the dissolution of feldspar grain (figure 5), and Carnian-Norian sandstones could be into late deep subsurface diagenetic (Group C\(^{[12]}\)). While, it could be interpreted as mature mesogenic B\(^{[11]}\), these sandstones interpreted as low part from stage III with a temperature around 95˚-120˚C with the depth burial around 2700m-4000m\(^{[14]}\).

6. Conclusion
Reservoir characteristics of sandstones could be determined by the diagenetic process, these processes could increase or even decrease the rock porosity. The important process is compaction, dissolution, and cementation by calcite, clay mineral, and iron oxide.

The compaction process could be dominant to influence the contact in grains, causes of carnian-norian sandstones could be compacted and only left less intergranular porosity, the compaction process could leave much fracture, so the secondary porosity couldn’t be formed dominantly. Due to not dominant secondary porosity, the dissolving process not occurs intensively, the dissolving only occurred in feldspar mineral dissolving that the amount not significant. The decrease of rock porosity getting decreases by cementation activity because of calcite, clay mineral, and iron oxide. The influence of diagenetic formed reservoir quality into the poorly.
Acknowledgments
The writer is feeling grateful to head and all of the geologist from Geological Survey Center, Geological Agency, Ministry of Energy and Mineral Resources, Indonesia could give a best chance to facilitate the writer when fill the field data and laboratory analysis. The writer also being thankful to all of the college lecturer from major Geological Engineering, Universitas Jenderal Soedirman, Purwokerto, Indonesia.

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