FACIES MODELING OF KAIS FORMATION LIMESTONE: A CASE STUDY OF KAFOR FIELD, WEST PAPUA, INDONESIA

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ABSTRACT: Facies modeling of Kais Formation limestone was carried out in the Kafor field, West Papua. Kais Formation limestone of Middle Miocene ages is the main reservoir that produces hydrocarbon in Kafor field. This field is located at Bintuni, West Papua. The objectives of this work are to perform detailed depositional facies analysis and to interpret the diagenesis process using rock typing for assessing the potential of the carbonate reservoir. Kais Formation limestone was classified into three members; Upper Kais, Middle Kais, and Lower Kais, which are associated with five different facies (i.e., shelf, front reef, inter reef, back reef, and core reef facies). The associated facies were interpreted as reefal platform carbonate. The reservoir quality was reviewed by facies distribution, petrography, and biostratigraphy. Our analysis shows that the Upper and Middle Kais were controlled by compaction and dominated by fractured porosity, while in contrast, the Lower Kais was controlled by dolomitization and dissolution diagenesis.

Keywords: Facies analysis, Kais Formation, West Papua Indonesia

1. INTRODUCTION

The study area is located in Kafor field, which is an onshore field situated 50 km northwest of Bintuni Bay. Kafor field is a former Dutch heritage operated until 1961 with the production of an open hole well. The location map of Kafor field, Bintuni Basin, West Papua is shown in Fig. 1. The first exploration well in the Kafor field is an old well discovered by Nederlandsche New Guinea Petroleum Maatschappij (NNGPM) around 1939-1940.

Currently, the 44 wells status is suspended (S/I) because they have a high water cut (about 98-99%), and only four wells are still producing by natural flow in a certain period. In 2014 two wells were drilled with the final results of a dry hole and water production. To develop this field, an assessment and a review reservoir model have been conducted based on the facies analysis using seismic and well data, which is focused on Kais Formation limestone.

In terms of the petroleum system, the source rock in the Bintuni Basin originated from a rich clay stone of organic matter from Permian Pre-Tertiary rocks, which is equivalent to the Upper Aifam (Ainim and Aifat) and Jura-aged rocks, which is equivalent to the Tipuma-Bottom Formation [1]-[5]. The source rock of the Aifam group is believed to produce hydrocarbon gas (gas prone) while Jurassic source rock tends to produce oil (oil prone) [6]-[8]. The main tertiary reservoir in the Bintuni Basin is the Kais Formation of carbonate rock with the Late Miocene to recent Steenkool clay as a trap for the oil accumulation in the New Guinea group [9]-[12].

In this work, we performed detailed depositional facies modeling and interpretation of the diagenesis process using rock typing for assessing the potential of the carbonate reservoir. We used six well log datasets and two-dimensional (2D) post stack seismic datasets that cover the study area.
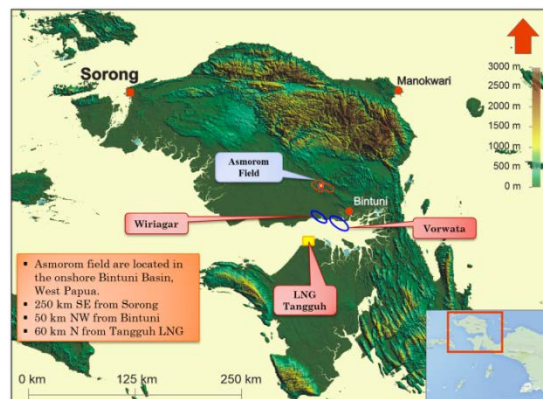

Fig. 1 Location map of Kafor field, Bintuni Basin, West Papua. The red polygon indicates the study area.

2. FACIES ANALYSIS OF KAIS FORMATION

The facies analysis was carried out by drawing a correlation line among wells based on the sequence stratigraphic approach, which connects the presence of stratigraphic intervals based on similarity in time or stratigraphic position. This

well correlation is intended to reconstruct sub-surface geological conditions in terms of structures and stratigraphy and in terms of paleogeography at a certain stratigraphic age.

In this study, correlations among wells were performed on the Upper Kais, Middle Kais, and Lower Kais formations by integrating geological and geophysical data. Figure 2 shows the well correlation of Kais Formation limestone through six wells over section A-A'. The geophysical data, used in this study are the result of amplitude attribute analysis, while the geological data used are the result of well data analysis, petrographic analysis, biostratigraphy, and drilling well reports. The interpretation of the reef zone in Kais Formation limestone was carried out using the evaluation and identification data of all fossil objects contained in each zone. The interpretative approach shows that Kais Formation limestone is a carbonate platform overlaid by the Steenkool formation. Referring to the previous study, the facies consist of back reef facies, core reef facies, fore reef facies, and shelf margin facies [13]. The detailed identification of this carbonate platform is explained as follows:

- Back reef area was identified by fossils of echinoids, the reef, coral, and algae.
- Fore reef area was identified by fossils of foraminifera, pelecypods, algae, and coral.
- Core reef area was identified by fossils of shell, coral sand, and coral.
- Inter reef area was identified by fossils of large and small foraminifera, mollusks, algae, and coral..
- Shelf margin area was identified by fine-grained deposits, predominantly clay, small foraminifera, and fine limestone grains.
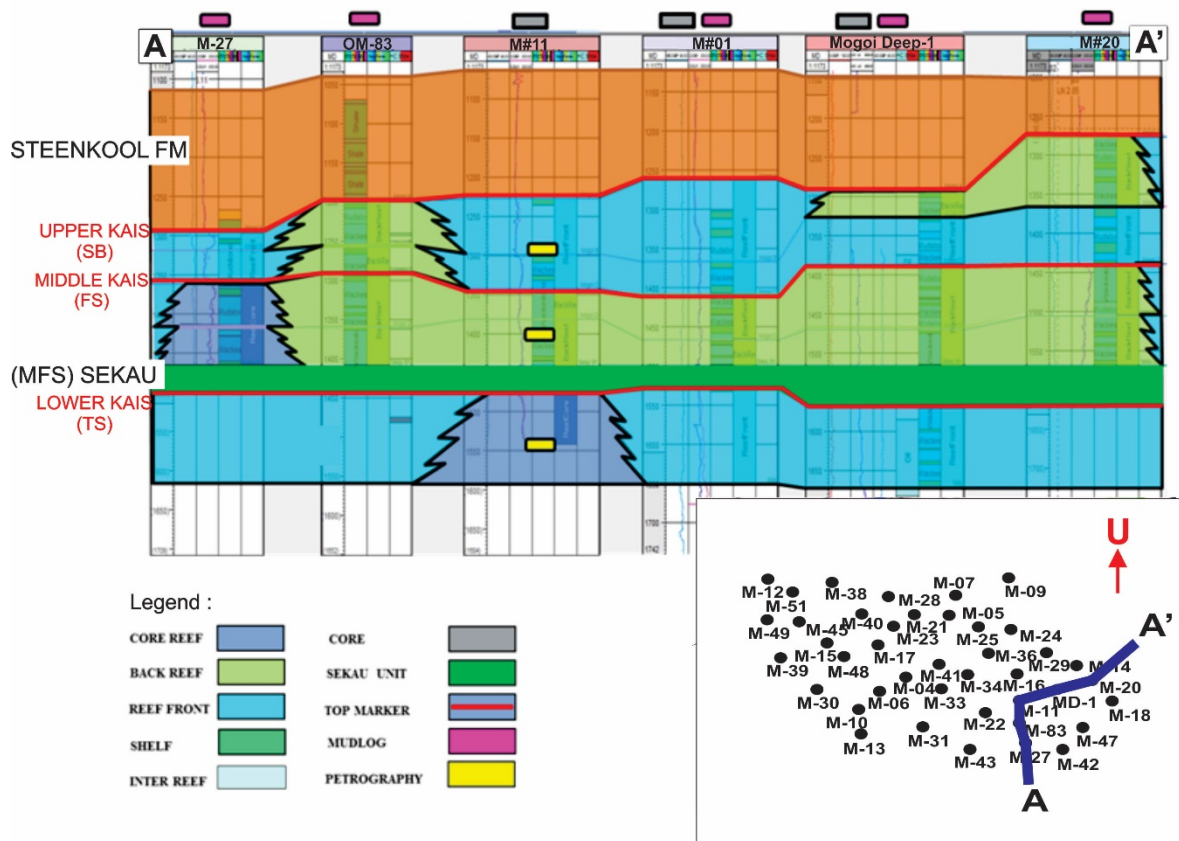

Fig. 2. Well correlation of Kais Formation limestone over section A-A'.

The lateral distribution of the facies was guided by the isopach map, which is determined from the interpretative approach on the seismic section [14]. The isopach map of the Upper Kais, which is a carbonate buildup, developed only at the high area of the Kafor field, which is shown by the limited area in Fig. 3a. On the other hand, the isopach map of the Middle Kais is depicted in Fig. 3b and the Lower Kais is displayed in Fig. 3c. These two isopachs were characterized as a carbonate platform. The difference between the Middle and Lower Kais is controlled by diagenesis of the carbonate, in which the Lower Kais was dominated by dolomitization.
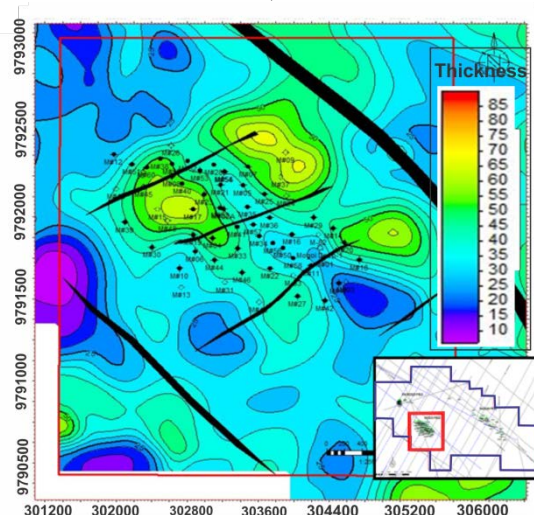
2.1 Facies of Upper Kais Limestone

The Upper Kais has good porosity up to 7.2% in the southeastern part of Kafor field around the

MD-1 well, whereas in the northwestern part around the M-15 well there is relatively low porosity (<3.6%). This indication was reasonable because the area of MD-1 well was located relatively near to the mainland, so the influence of fresh water was more dominant when the carbonate underwent sub-aerial diagenesis.

Based on the well log evaluation of MD-1 well, which is illustrated in Fig. 4a, the Upper Kais interval has high resistivity (>100 Ohmm). The Upper Kais limestone has an interval depth of 358 to 419 m. This interval was interpreted as a carbonate buildup. The petrographic analysis shows that this carbonate can be categorized as shaly limestone that consists of argillic with clay intersection lamination. The results of the core evaluation, which is presented in Fig. 4b and Fig. 4c, show that the Upper Kais layer was composed of white to light gray limestone, micrite containing fossils, microcrystalline to very fine crystalline, coral fragments, stromatolites, argillaceous dolomitic, with oil spots. Minor oil indicates low-quality oil, consisting of 5% dark brown oil spots and maximum gas to a total of 88 units (C1 to C5).
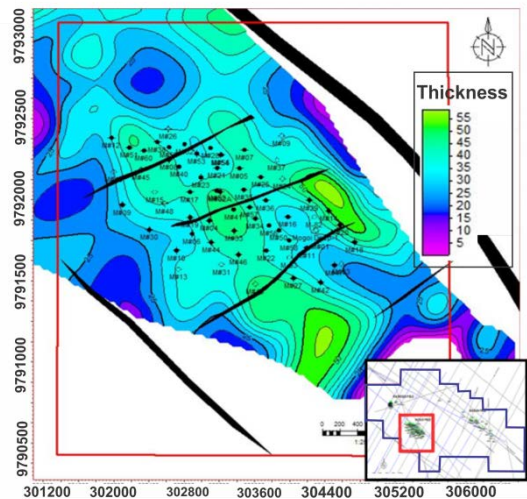
a)

b)
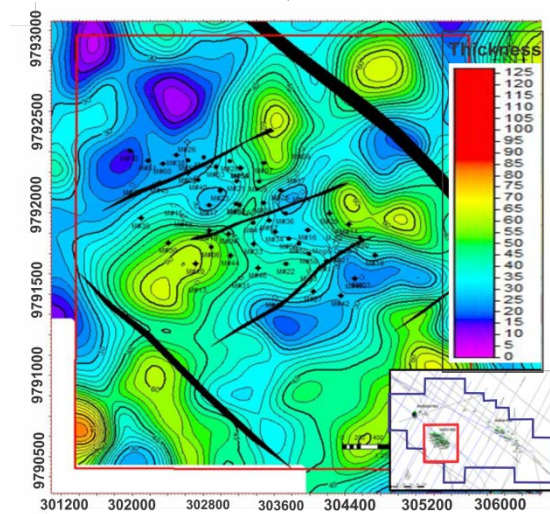
c)

Fig. 3 Isopach maps of Upper Kais (a), Middle Kais (b), and Lower Kais (c).

2.2 Facies of Middle Kais Limestone

Middle Kais limestone has fair to good porosity up to 6.8% in the northern part of Kafor field around the M-25 well. In contrast, in the southern part of the field around the M-13 well the porosity is relatively poor (<3.7%). Lithofacies analysis using thin section data and core description has identified packstone, small foram packstone, and mudstone [15]. The process that controls diagenesis is burial and compaction, which result in the porosity of 6-9% and permeability of 0.1-7.1 mD. The content of fossil consists of algae, coral, shell, large foram, and fossil fragments.

The Middle Kais limestone is in the intervals of 419 to 462 m and it is interpreted as a carbonate platform. Similar to the Upper Kais, this limestone consists of a shaly limestone. There is argillic with clay intersection lamination. This interval is a productive layer that has produced oil in the Kafor field. The results of the core descriptions are white to gray limestone. There is micrite with fossil fragments, some dolomite and very argillic with clay intersection lamination. There is no indication of matrix porosity from the cutting. Minor oil indicates low-quality oil, consisting of 5% dark brown oil spots and maximum gas to the total of 88 units (C1 to C5).

2.3 Facies of Lower Kais Limestone

Lower Kais limestone has very good porosity up to 9.8% in the northern Kafor field around the M-7 well, while in the southern part of the field around the M-42 well, the porosity is relatively moderate (<5.7%). Lithofacies analysis using thin section data and core description has identified

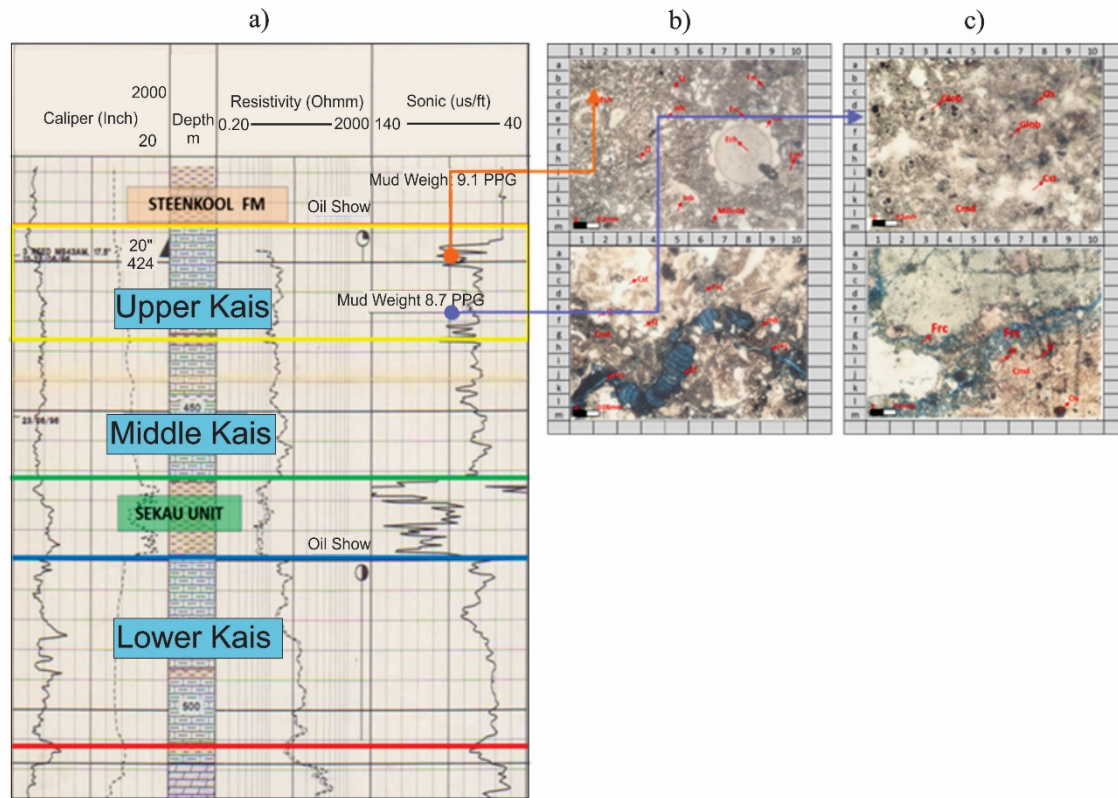dolomitized wackestone, packed foram and dolostone [15].

Fig. 4 Well log analysis of MD-1 well with (a) SP and resistivity log and lithology type in the Upper Kais limestone interval. Description of the thin incision of the core from the microscopic analysis for thin layer wackestone from depth 425 m (b) and 434 m (c).

The diagenesis process that was controlling this zone is dolomitization and dissolution, with a porosity of 8-10% and permeability of 0.1-107 mD. The content of fossils includes algae, foram, bryozoa, coral, and fossil fragments.

The Lower Kais limestone is a productive zone that has the appearance of oil. The results of the core descriptions present light gray to white limestone, partially dotted, fine crystalline to very fine, very fine grain to graded on the bottom, lime texture in several parts, argillic, pyrite minerals, and calcite fragment. There is no indication of the matrix porosity. Almost 40% of the fluorescent mineral shows a gradation color from yellow to gold, which is indicated by scattered oil spots such as brown oil spots with a slightly pale residue. This rock was composed of black to gray clay and its texture ranges from soft to moderately hard and decreases throughout the interval. This rock has a gas content from 3 to 66 units (C1-C5).

3. RESULTS AND DISCUSSION

3.1 Facies Modeling

The facies modeling has been performed on the following three zones, Upper Kais, Middle Kais and Lower Kais. The model was generated based on the lithologic interpretation from biostratigraphic and petrographic data, which is integrated with the results of isopach maps and root mean square (RMS) attributes.

The facies modeling for the Upper Kais is illustrated in Fig. 5.a. The light blue color represents fore reef facies, dark green represents shelf facies, and light green represents back reef facies.
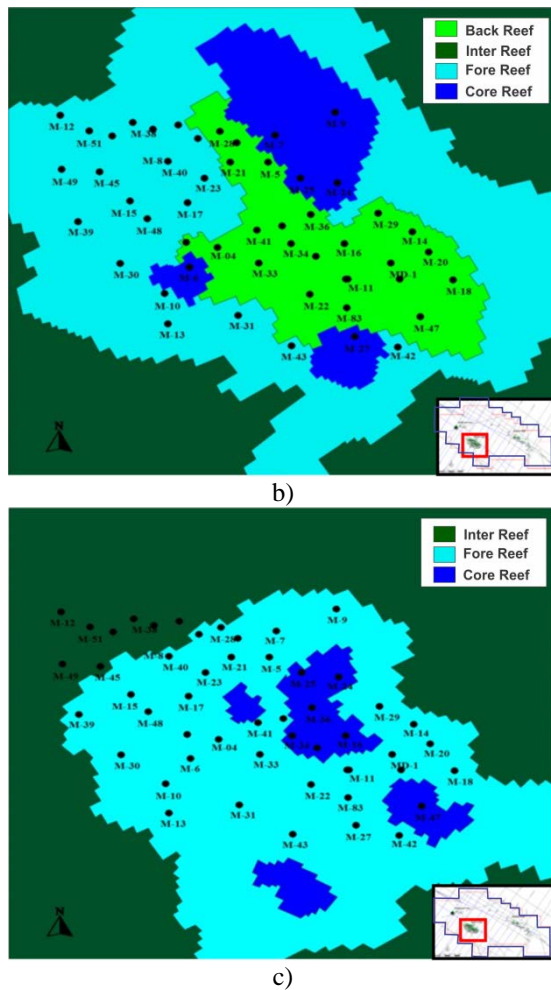

a)

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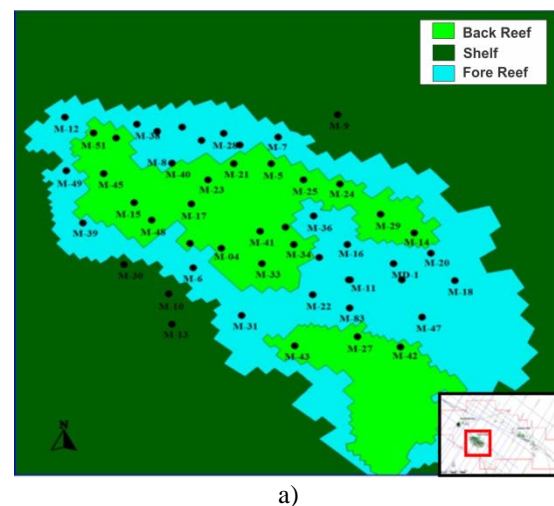
Fig. 5 The result of facies modeling for Upper
Kais limestone (a), Middle Kais limestone
(b), and Lower Kais limestone (c).

The Upper Kais was interpreted as a carbonate buildup where the shelf facies boundary represents the maximum sea level. There are two separate back reef facies on the northern and southern part. The fore reef facies is considered to be the best reservoir, with wackestone and packstone with a porosity of about 8-11%.

The facies modeling for Middle Kais limestone is shown in Fig. 5b. The light blue represents fore facies, the dark green represents the inter reef facies, light green represents back reef facies, and the dark blue represents core reef facies. It can be seen that from the Upper Kais to Middle Kais there was a decreasing sea level in which no shelf facies change to inter reef facies. Furthermore, there exists a core reef that was separated between the fore reef facies and back reef facies. The fore reef facies is considered to be a good reservoir with packstone and small foram packstone with a porosity of about 6-9%.

Fig. 5c is the facies model of Lower Kais limestone. The light blue color represents fore reef facies, dark green represents inter reef facies, and

the dark blue represents core reef facies. Similar to the Middle Kais, there are no shelf facies that indicate a decreasing sea level. Furthermore, the back reef facies disappear in the Lower Kais. The fore reef facies are considered to be good reservoirs with larger lithologic foram packstone and packstone with a porosity of about 8-10%.

3.2 Effective Porosity Modeling

The effective porosity modeling is carried out based on the primary data of routine core analysis (RCAL). Seven wells that have RCAL data are shown in Fig. 6. The porosity of the other wells that have no RCAL was estimated using a statistical approach based on the mode value of the porosity at each depth sample. The comparison between the estimated porosity and a mode value of porosity for the M-05 well from RCAL is shown in Fig. 7.
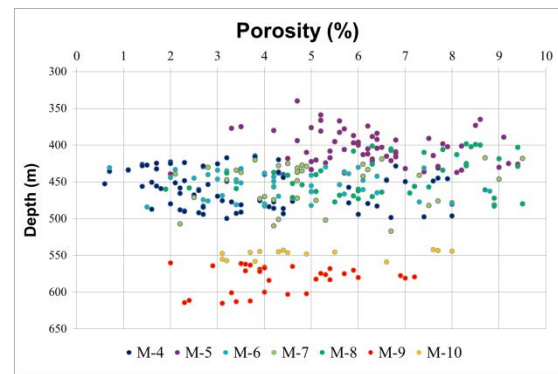

Fig. 6 Porosity data of routine core analysis.

Unfortunately, most of the wells have no neutron, density and sonic log, which is used to calculate the effective porosity, so we use the empirical relation between resistivity and porosity to estimate their effective porosity. Fig. 8 shows the relationship between the effective porosity and resistivity, which is stated in Equation (1). Using Equation (1), the effective porosity for all wells is then estimated.

$$Por = -0.1647 \times Res + 7.2446 \qquad (1)$$

The effective porosity (PHIE) was modeled directly by weighting cokriging from inverted seismic data and constrained by the previous facies distribution. The distribution of porosity model, which was guided by the RMS data, isopach maps, inverted seismic data and facies model, is in good agreement with the geological condition. The major orientation of the porosity distribution shows a similar trend to the facies modeling result, which has the relative direction of NE-SW.
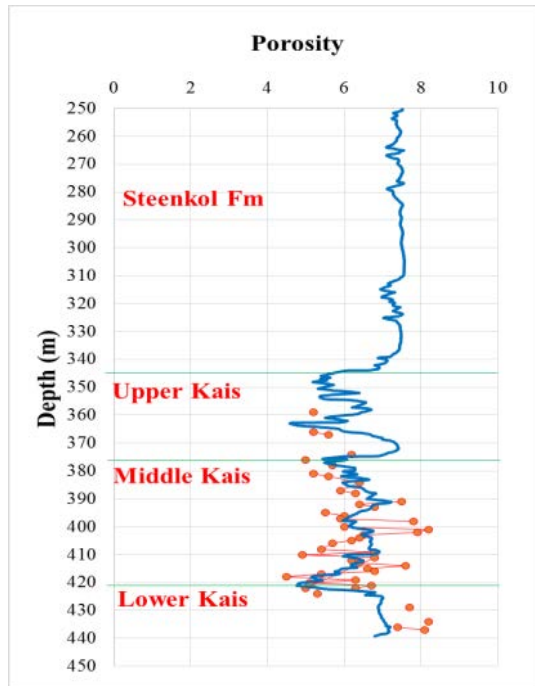
Fig. 7 Total porosity, approximated by the statistical mode of RCAL porosity for M-05 well.

The distribution of effective porosity modeling is shown in Fig. 9. The effective porosity map for the Upper Kais layer is displayed in Fig. 9a and has an average porosity of 5.7%. Fig. 9b shows the porosity map for the Middle Kais layer with an average porosity of 6.3%. In addition, the average porosity of the Lower Kais is 7.2%, which is shown in Figure 9c. In general, the orientation of the effective porosity map is significantly constrained by the facies model.
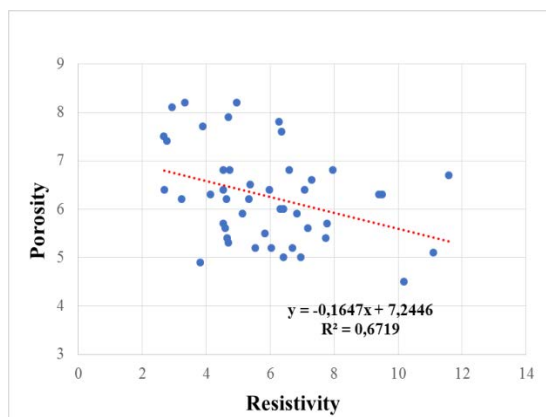

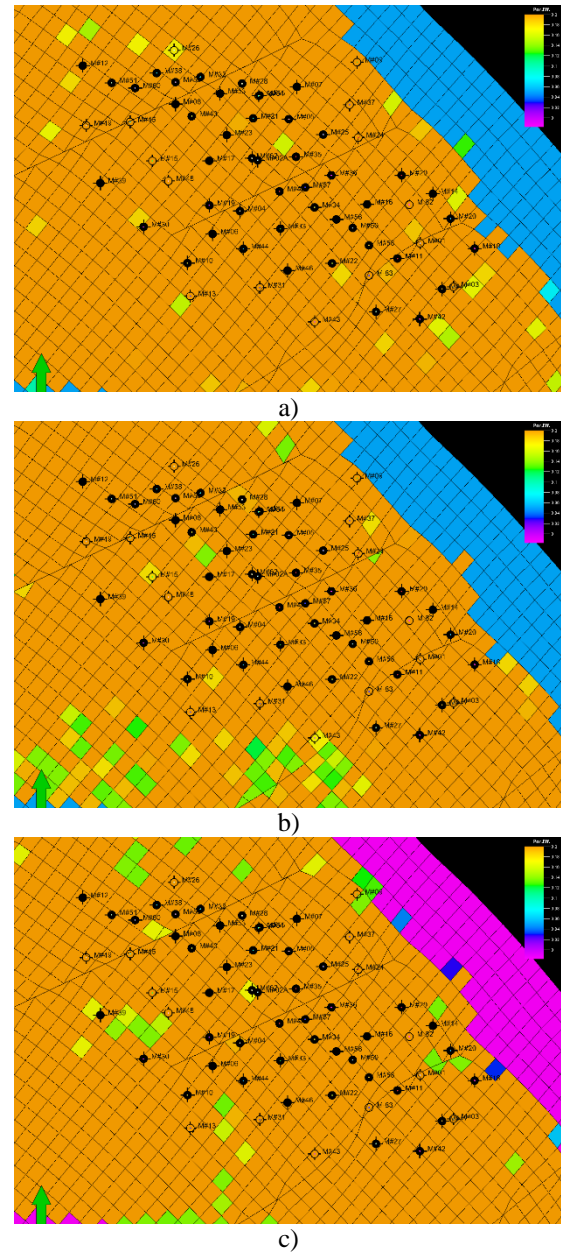Fig. 8 Relationship between effective porosity and resistivity for M-05 well.

a)

b)

c)

Fig. 9. Effective porosity map for (a) Upper Kais (b) Middle Kais, and (c) Lower Kais.

4. CONCLUSIONS

Facies modeling of Kais Formation limestone has been successfully performed in the Kafor field, Bintuni Basin, West Papua. The detailed depositional facies was properly mapped throughout the study area, which helps to delineate the distribution of carbonate reservoirs. Our interpretative approach shows that Kais Formation limestone is a carbonate platform, which is classified into three units: Upper Kais, Middle Kais, and Lower Kais. The detailed facies analysis for each unit shows that Upper Kais limestone consists of the fore reef, shelf, and back reef, while

the Middle Kais limestone consists of the fore reef, inter reef, back reef, and core reef. Further, the Lower Kais limestone consists of the fore reef, inter reef, and core reef.

Referring to the petrography analysis, it can be stated that the Upper Kais and Middle Kais are significantly controlled by a diagenetic compaction process with fractured porosity, while the Lower Kais is controlled by diagenetic dolomitization with dissolution by fractured porosity.

In general, the porosity modeling shows that the orientation of effective porosity is significantly constrained by the facies model, which has the relative direction of NE-SW. The distribution of effective porosity for the Upper Kais layer has an average porosity of 5.7%, while the Middle Kais layer has an average porosity of 6.3%. In addition, the average porosity of the Lower Kais is 7.2%.

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