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Three-Dimensional Reservoir Modeling Based on Geostatistical Analysis to Determine Volumetric Oil in Place of Alpha Zone

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***Abstract*—The research of three-dimensional (3D) reservoir modeling of Alpha Zone is located in Balikpapan Formation Kutei Basin, East Kalimantan. The lithological analysis shows that Alpha Zone consists of sandstones, mudstone/shale and coal, which vertically and laterally distributed based on 206 wells and 3D seismic. Based on the results of petrophysical analysis, well and controlled correlation with seismic horizon picking, produced a pattern of fault trending NE-SW relative to the pattern trending anticline structure relative North-South, where the distributions of Alpha Zone have an average gross thickness of 9-15 meter and average net sandstone is 4-11 meter. Lithofacies approach method also used, which divided into three lithofacies sandstone, shale, and coal, which have sandstone facies distributions NW-SE, where the percentage of the distributions is 20%. The 3D reservoir modeling framework conducted is based on the reservoir depth structure maps generated from picking seismic and controlled by the correlation between wells. Distribution of reservoir properties include facies, Vshale, porosity, and water saturation (Sw), in making the property distribution is based on the analysis of the distribution wells using geostatistical variogram, where the results are validated against production data, so we will get an integrated 3D reservoir modeling of Alpha Zone. Furthermore, based on the volumetric determination of Original Oil in Place (OOIP) in Alpha Zone acquired 2.35 MMbbl.**

***Index Terms*—geostatistical analysis, reservoir modeling, facies, petrophysic**

I. Introduction

By the increasing of oil fuel consuming, oil reserve existence is getting rare. This condition makes several oil and gas companies do field development in potential oil field continuously and search for new potential oil reserve. Balikpapan Formation is located at Kutei Basin which is precipitated at lower delta plain until delta front, is potential formation that contain of hydrocarbon which is give big enough contribution. Observation study and search for prospects zone (zone that contain hydrocarbon) in this formation is developed continuously in order to increase the reserve and production of oil and gas [1]-[6].

Three-Dimensional (3D) reservoir modeling at Alpha zone is one of observation study in order to know reservoir characteristic, by integrating the well data and seismic data so we know the structure pattern and reservoir properties distribution (even in vertical or lateral) in detail [1], [3], [4], [6]. Based on that analysis, we can do Original Oil in Place (OOIP) determination even in structural or stratigraphy trap at Alpha zone of Balikpapan Formation. In general, the Alpha zone is located at Kutei Basin, East Kalimantan as shown in Fig. 1. The final goal of this research is to make structural model and distribute the reservoir property in 3D model, and determine OOIP in volumetric.

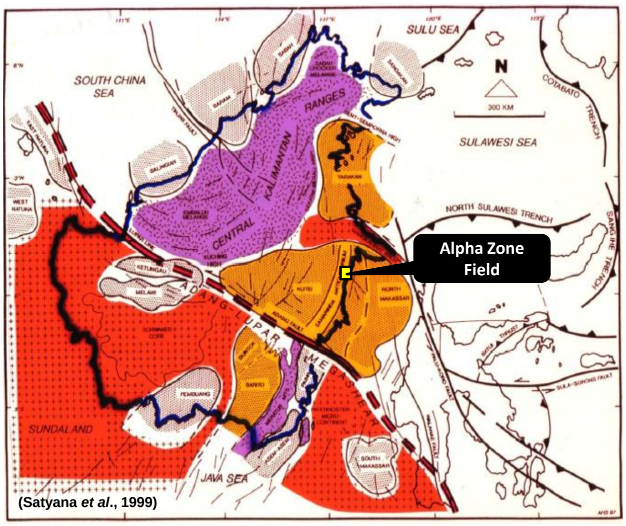

Figure 1. Location of observation study [6].

II. Geological and Regional Stratigraphy

Kutei Basin is the widest and deepest basin in Indonesia. This basin is bounded to the west by Kuching Uplift, to the North by Mangkalihat Uplift, to the South by Adang-Lupar Mega Shear and to the East by Makassar Straits [2], [5], [6].

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A. Geological Regional Structure

Geological regional structure of Kutei Basin is influenced by the movement to the west of Sulawesi Island which is sub-ducted by the movement of Pacific Ocean to the west. The active movement of Pacific Ocean Crust activates the left strike-slip fault Palu-Koro, and influences the geological structures that develop in Kutei Basin as shown in Fig. 2.

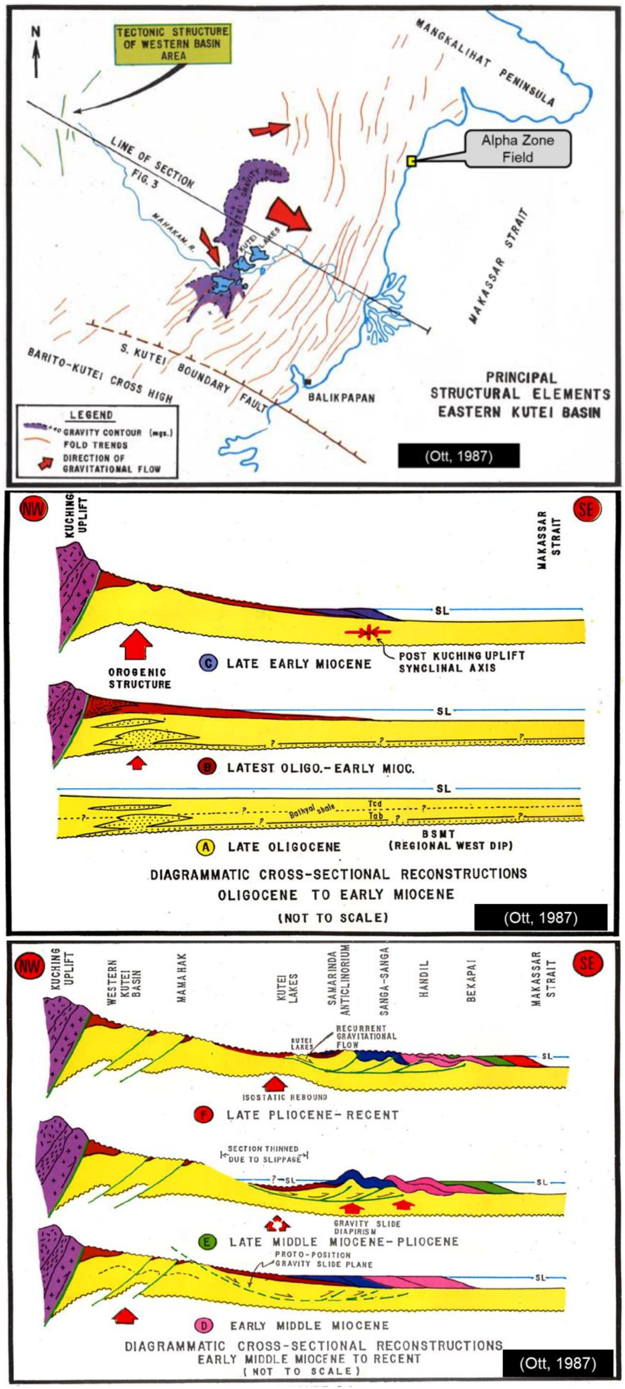


Figure 2. Kutei basin development [2], [5], [6].

1) Thrust Faults

Thrust Faults that develop at Kutei Basin is oriented N-S until NNE-SSW and up to west and east direction. These faults develop during Pleistoceneas result of the compression movement of Sulawesi Island to the west direction. So, the faults are made which is *detachment* and develops into growing thrust fault.

2) Folds

This structure is oriented N-S until NNE-SSW. The fold structure at Kutei Basin is caused by the active compression of Sulawesi to the West direction among the Pliosen until now.

B. Regional Stratigraphy

Regional stratigraphy of Kutei Basin refers to earlier observation by Satyana *et al.*, [6] can be described from the oldest to youngest as follows:

1) Basement - Pre-Tertiary

The basement in East Kalimantan Basin is consisted of granite igneous rock and metamorphic rock. This rock makes half graben or graben among the Eocene.

2) Beriun Formation - Eocene

Beriun Formation is deposited uncomfortably above the basement. The lower part of this formation is consisted of tuff sandstone which crosses bedding by shale. The upper part is consisted of shale. This formation is deposited at land along the Eocene period.

3) Atan Formation - Early Eocene

This formation is deposited conformably above the Beriun in transgressive condition, so that the deposition environmental is transition. Lower part of Atan Formation is consisted of shale and reefs limestone at above. The top of this formation is consisted of tuff sandstone.

4) Marah Formation - Late Oligocene

The lower part of this formation is consisted limey-shale inserted with tuff sandstone crosses bedding by reefs limestone. While, at the upper part is consisted of limey shale inserted with tuff shale. This formation is deposited along Late Oligocene and lay above the Atan Formation conformably in trangressive condition.

5) Pamaluan Formation - Early Miocene

The sea condition is getting more transgressive (deeper) deposits the sedimentation conformably by layers limit that deposited gradually. Pamaluan Formation is above Marah Formation along Early Miocene. This formation is consisted of shale at the lower part, while at the upper part is consisted of shale inserted with thin limestone.

6) Bebulu Formation - Early Miocene Upper Part

This formation is consisted of limey shale (marl) at the lower part, while at the upper part is consisted of limestone inserted with marl. This formation is deposited at Early Miocene Lower Part and lay conformably above Pamaluan Formation with layer limit that deposited gradually.

7) Pulubalang Formation - Middle Miocene Lower Part

This formation is deposited conformably above Bebulu Formation at regressive sea condition. So, this formation is deposited in transition till deltaic environment. This formation is consisted of sandstone inserted with thin shale at the upper part, while at the upper part is deposited sandstone inserted with limestone. Pulubalang formation is deposited along Middle Miocene Lower Part.

8) Balikpapan Formation - Middle Miocene Upper Part

In transgressive condition, Balikpapan Formation is deposited conformably above Pulubalang Formation in fluviatile environment till transition (deltaic). This formation is consisted of sandstone inserted with shale along the Middle Miocene Upper Part. This formation is the target formation of Sangatta Field.

9) Kampungbaru Formation - Late Miocene until Pliocene

This formation is deposited conformably above Balikpapan Formation in land till deltaic environment. This formation is consisted of sandstone interlaminated with shale and coal along Late Miocene until Pliocene.

10) Mahakam/Alluvial - Recent

This alluvial is deposited uncomfortably above the Kampungbaru Formation as the result of weathering, erosion, transportation from the older formation and is deposited along the river flow. The regional stratigraphy of Kutei Basin [6] is shown in Fig. 3.

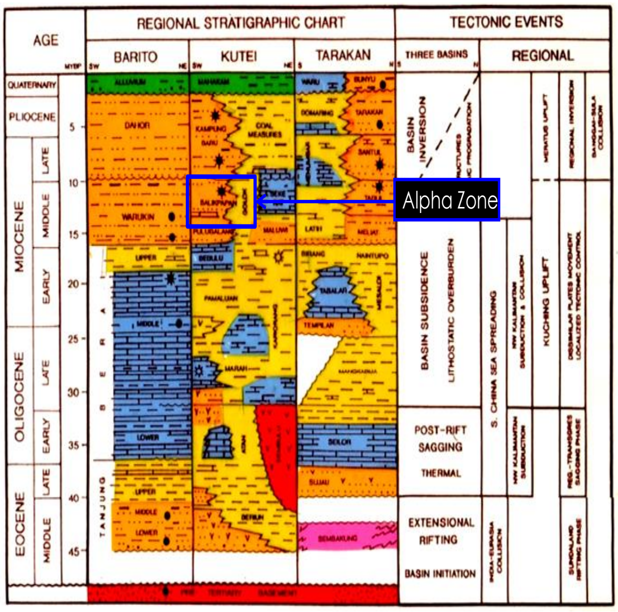


Figure 3. Regional stratigraphy of Kutei basin [6].

III. Methodology

Three-Dimensional (3D) reservoir modeling of Alpha zone is built based on well data (206 wells) 3D seismic data, whereas both data is interconnected. In making 3D reservoir model refers to work structure that has been made by SKK Migas [7], [8], and also [9] as shown in Fig. 4. The procedure is as follows:

a. *Structural Modeling*: making structural model, such as *3D grid (pillar gridding and fault modeling, make horizons, layering, make fluid contact)*.

b. *Property Modeling*: making property distribution on structural model which has been made before, such as *scale up well logs, data analysis, facies modeling, petrophysic modeling (Vshale, PHIE, Sw)*, [10], [11].

c. *Volumetric Determination*: Original Oil in Place (OOIP) determination in volumetric.

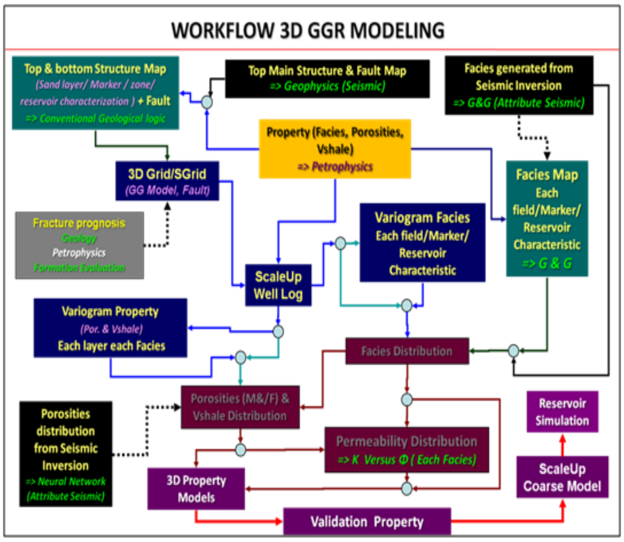


Figure 4. Workflow of 3D modeling of SKK Migas [7], [8].

IV. Results and Discussion

Three-Dimensional (3D) reservoir modeling of Alpha zone in general is divided into three main steps such as structural modeling, property modeling, and volumetric calculation. Structural modeling is done for making reservoir structural model in 3D, while property modeling is used for fill the 3D structure model with properties from well, such as facies, Vshale, Porosity, and Water saturation (Sw).

A. Structural Modeling

1) Mapping

Mapping is used for making surface map from well marker as well correlation result and seismic interpretation.

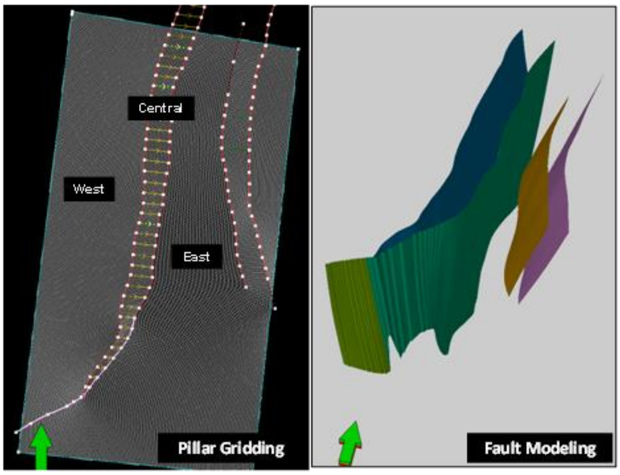


Figure 5. Pillar gridding and fault modeling.

2) Pillar Gridding and Fault Modeling

In this step is done by making 3D mesh which called skeleton that is going to be reference in making 3D grid. The grid size is 50 m x 50 m, because the well distribution is close enough. The results of this process are three skeletons, such as top, mid, and base. This result will be a reference in building 3D grid geometry. Fig. 5

shows the pillar gridding process and the result of skeleton from this process. Alpha zone is an anticline which has two big faults-oriented North East - South West (major), also two faults (minor). From those faults are divided into three blocks, such as West Block, Middle Block, and East Block. The fault structure pattern is from seismic interpretation result.

3) *Make Horizons*

In this step is made 3D structural model Alpha zone at layers which can be done seismic interpretation, by combining mapping result map and faults model. Fault modeling result in 3D Structure is made at pillar gridding process. Make horizon on the upper limit and lower limit has been done by *picking seismic*. Fig. 6 shows the process at make horizons.

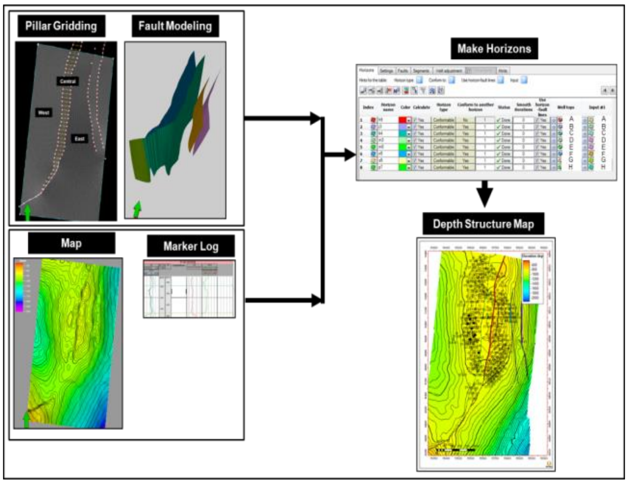


Figure 6. Make horizons process.

4) *Make Zones*

In *Make Zones* step is done to layers which cannot be made from seismic interpretation. Zonation Process is controlled by depth structural map which has made and marked from the well. Zonation process is shown at Fig. 7, while structural map as zonation result is shown in Fig. 8.

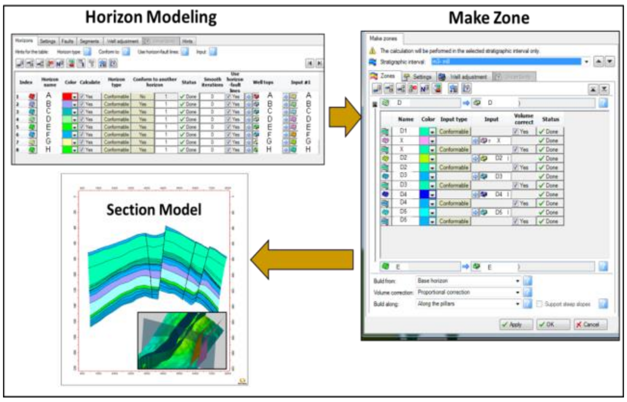


Figure 7. Make zone process.

5) *Layering*

Layering use for making thinner and more detail layers inside each reservoir zone. The layering thickness is going to be cell thickness, is the average well log properties data interval thickness which is modeled. Alpha zone is divided into 18 layers, average thickness is 0.5 m, which means the log property data will be averaged every 0.5 m thickness. Fig. 9 shows the layering result.

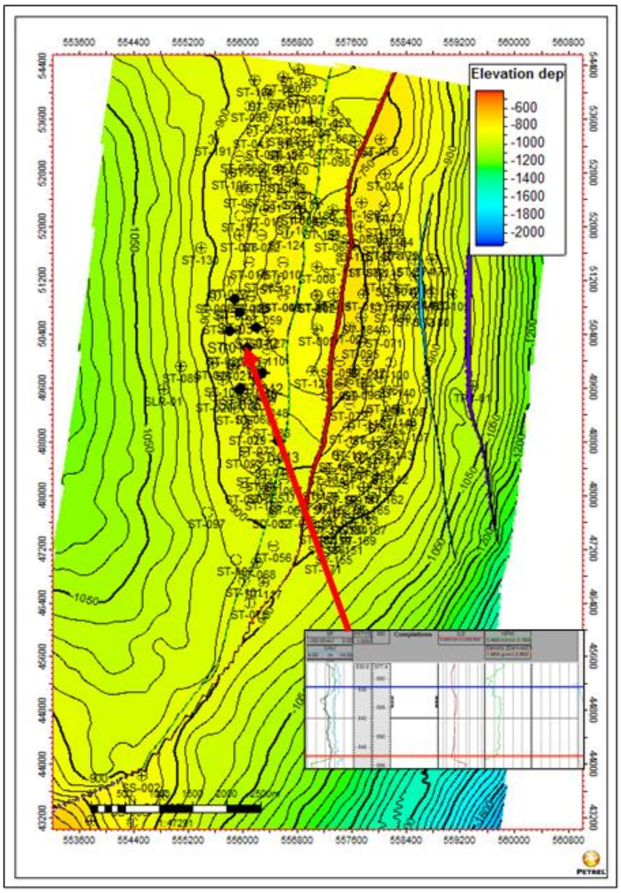


Figure 8. Alpha zone depth structure map.

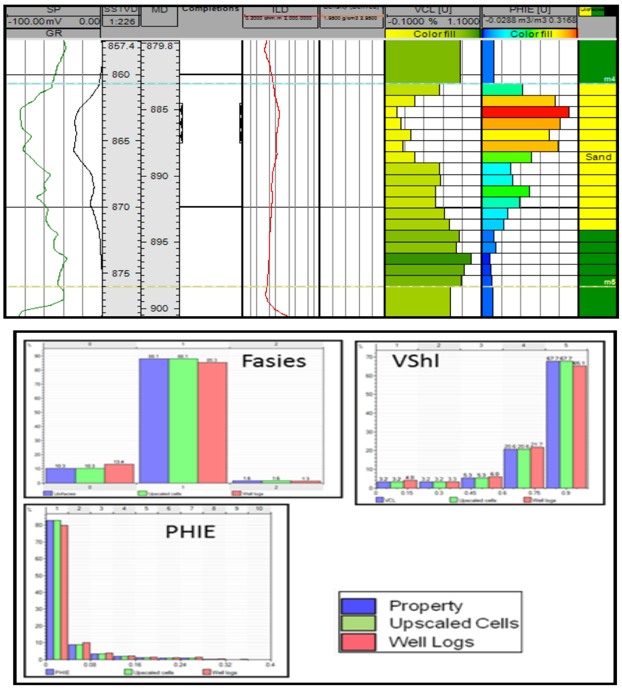


Figure 9. Layering and scale-up of well logs.

6) Fluid Contact Determination

Fluid contact that used is *Lowest Known Oil* (LKO), where the referenced well determination is based on well has ever produced oil. At Alpha zone has LKO limitations: -868 mss (West Block: Ref. A-018: perforations (884.5-887) m, was produces since April 1977, Qo: 244.59 bbl/d) and -821.47 mss (Middle Block: Ref. A-111: perforations (836-838) m, was produced. Qo: 220 bbl/d). Fig. 10 shows the fluid contact map of Alpha zone.

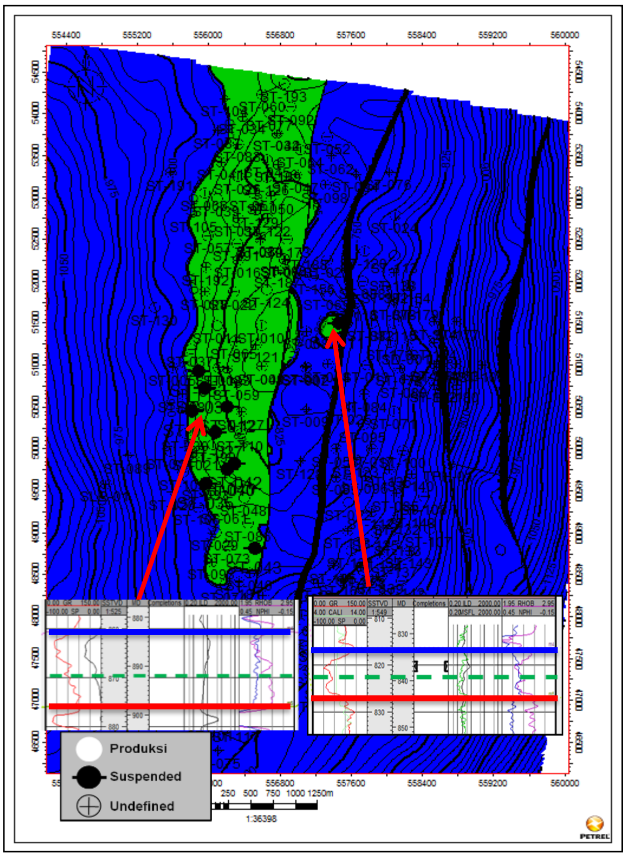


Figure 10. Fluid contact map of Alpha zone.

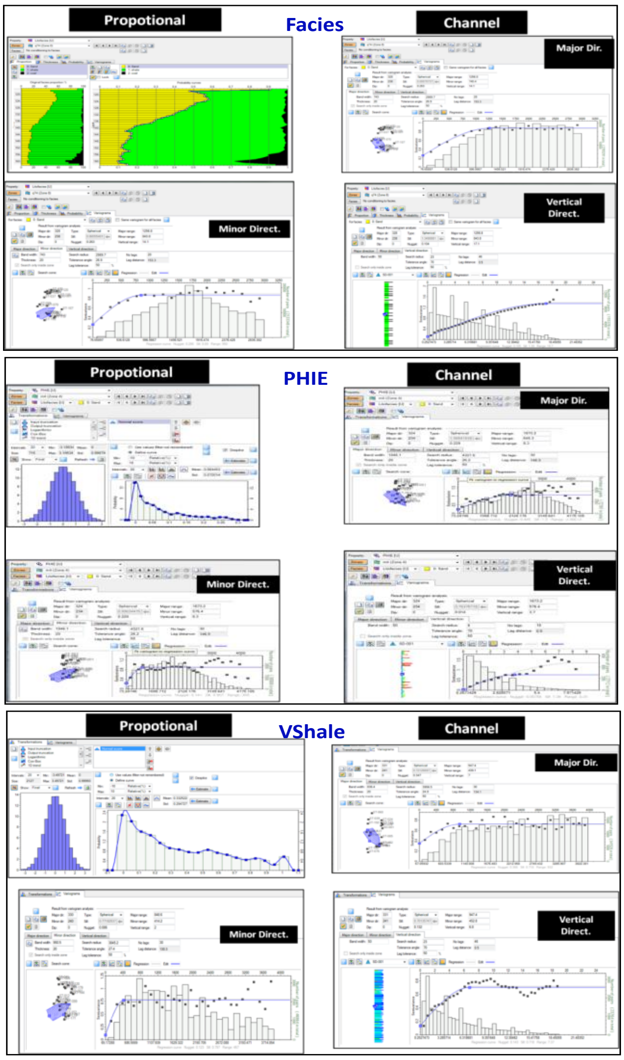
B. Property Modeling

1) Scale Up Well Logs

Scale Up is a process of averaging log value from well that has initial high vertical resolution, become one value for each cell that passed by well. This process is done for inputting properties data from well in 3D grid, and then will be distributed to all grid through property modeling process. Scale up is done for facies, Vshale, and PHIE. Validation of scale up well log result is done by observing the difference between original histogram log data (in red color) with scale up result (in green color) as was shown in Fig. 9 previously.

2) Data Analysis

Before distributed into all 3D grids, the properties data as result of *scale-up* process is analyzed, such as histogram, maximum-minimum, existence of *outlier* and its transformation, then to analyze the tendency of data distribution direction in spatial. We did variogram analysis in lateral and vertical. Results from variogram analysis are *major range*, *minor range*, *vertical range*, *nugget effect* and direction from *major range*. In determining major direction is based on sedimentation direction. Variogram geostatistical analysis is done for every facies property, so that the property distribution is controlled by facies distribution. At Alpha zone, variogram analysis is focused on sandstone lithofacies, variogram model that use is sill spherical type. Fig. 11 shows the analysis data and variogram at Alpha zone.



Propertiy	Fasies	Model Type	Major Dir.	Minor Dir.	Orientasi	Sill	Nugget	Major Range	Minor Range	Vertikal Range
Fasies			337	247	NW-SE	1	0.31	2370	1006.7	3.7
Vshl	Sand	Spherical	350	260	NW-SE	1	0.0022	1444.5	854.1	3.1
PHIE			324	234	NW-SE	1	0.014	1873.2	576.4	3.7

Figure 11. Variogram geostatistical analysis.

3) Facies and Property Modeling

The first property that made is facies. Facies identification in deterministic is done by dividing based on log characteristic (GR), where the facies classification is based on lithofacies, such as *sand*, *shale*, and *coal*. Facies pattern making use iso-facies map then uses as probability map in making *facies modelling trend*. 3D Facies distribution use SIS (Sequential Indicator Simulation) method and is controlled by well data from *scale-up* well log result which has been done variogram analysis. Fig. 12 shows the facies distribution process.

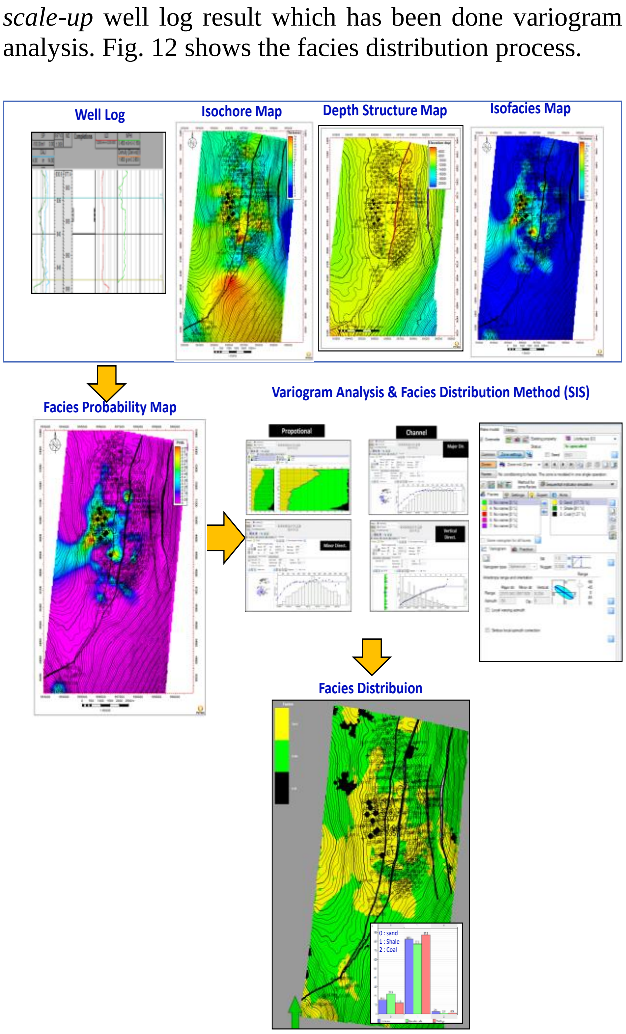


Figure 12. Three-dimensional (3D) Facies modeling process.

Petrophysic modeling is done in two methods, such as *geostatistical distributed* (V*Shale*, PHIE, Sw) and *calculated* (NTG). Petrophysic modeling, such as Vshale and PHIE by using result from *scale up well*. After this, will be done variogram analysis for each facies. Petrophysic properties distribution (Vshale and PHIE) use SGS (Sequential Gaussian Simulation) method which is *guided* by facies distribution. Property distribution process is shown in Fig. 13, while the results of facies and property distribution for *VShale*, *PHIE*, and Sw of Alpha zone is shown in Fig. 14.

C. OOIP (Original Oil in Place) Determination

Determination of OOIP is done in volumetric. Data that required for OOIP determination is porosity 3D model (PHIE), NTG, Sw, fluid contact data, and Boi data. In place determination of Alpha zone is done by making boundary based on iso-facies map, so that the calculation is done at sand facies in oil contact, is shown in Fig. 15. Based on OOIP determination of Alpha zone, the result is 2.35 MMbbl (millions barrel), with details: Vb (m3):28.7x10^6, net volume (rm^3): 11.8x10^6, Pore Volume (rm^3): 0.96x10^6, HCPV oil (rm^3): 0.41x10^6, Boi: 1.1 bbl/STB.

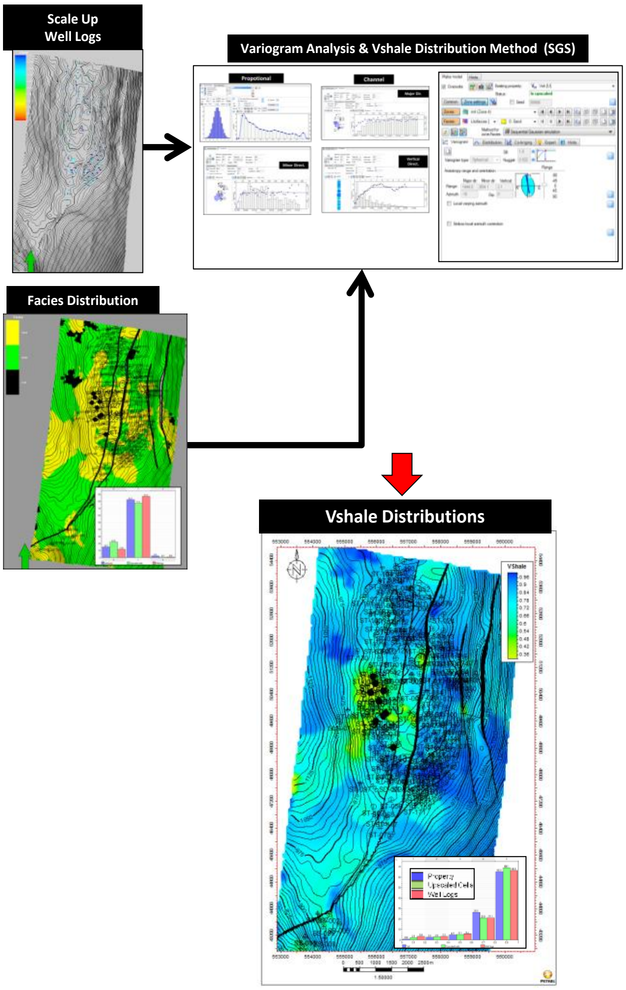


Figure 13. 3D Property modeling process.

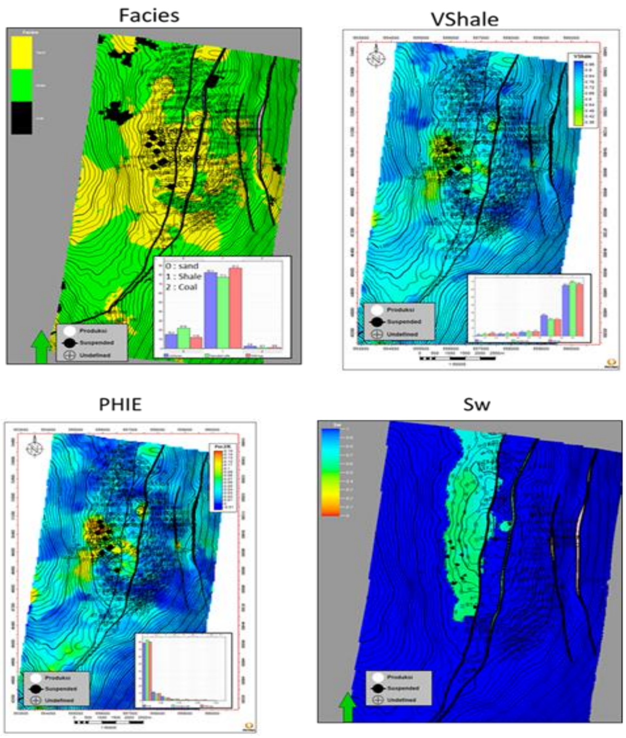
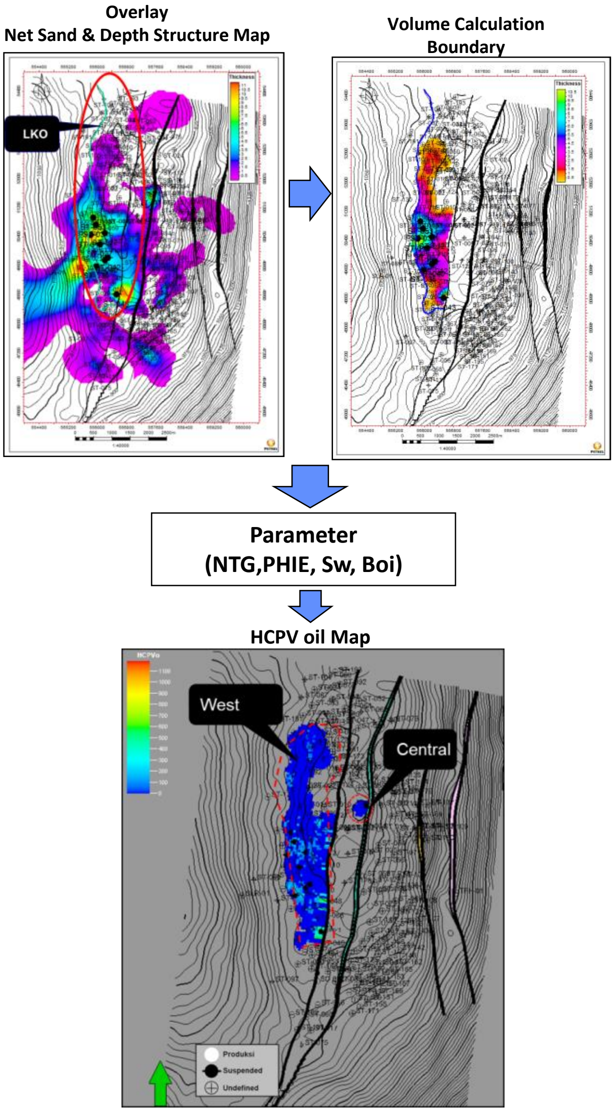


Figure 14. Property distribution of Alpha zone.



Bulk Volume (m3)	Net Volume (m3)	Pore Volume (rm3)	HCPV Oil (rm3)	OOIP (MMSTB)
28,690,740	11,771,311	961,807	410,664	2.35

Figure 15. Alpha zone OOIP determination result.

V. Conclusion

Based on the analysis and discussion, there are some results as a conclusion as follows:

1) Faults pattern in Alpha zone has oriented N-S until NNE-SSW and up to west and east direction. The thickness of clean sandstone is about 4-11 meters.
2) The types of traps on Alpha zone are stratigraphy and structural trap.
3) Facies identification at Alpha zone uses lithofacies, such as sandstone, shale, and coal based on *log cycle.*
4) Based on geostatictical analysis use variogram model with *sill spherical* type, is oriented 320^0 in general direction, and for facies distribution use SIS method, while in petrophysic distribution use SGS method.
5) Based on volumetric calculation from 3D model, the result of OOIP is 2.35 MMbbl.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The authors were collaborating to produce this manuscript in terms of each background competency and experts. This study is a part of the research in order to further developing of the oil and gas field in Alpha Zone. Hence, the application of geostatistical analysis to model of the reservoir and to know of the reservoir potentials is very important as once of the factor to be considered. The study provides 3D reservoir modelling of Alpha Zone and the volumetric oil in place. Then, based on the study we can continuing conducted of reservoir simulation and make strategic further development plan in the Alpha Zone to increase oil recovery.

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