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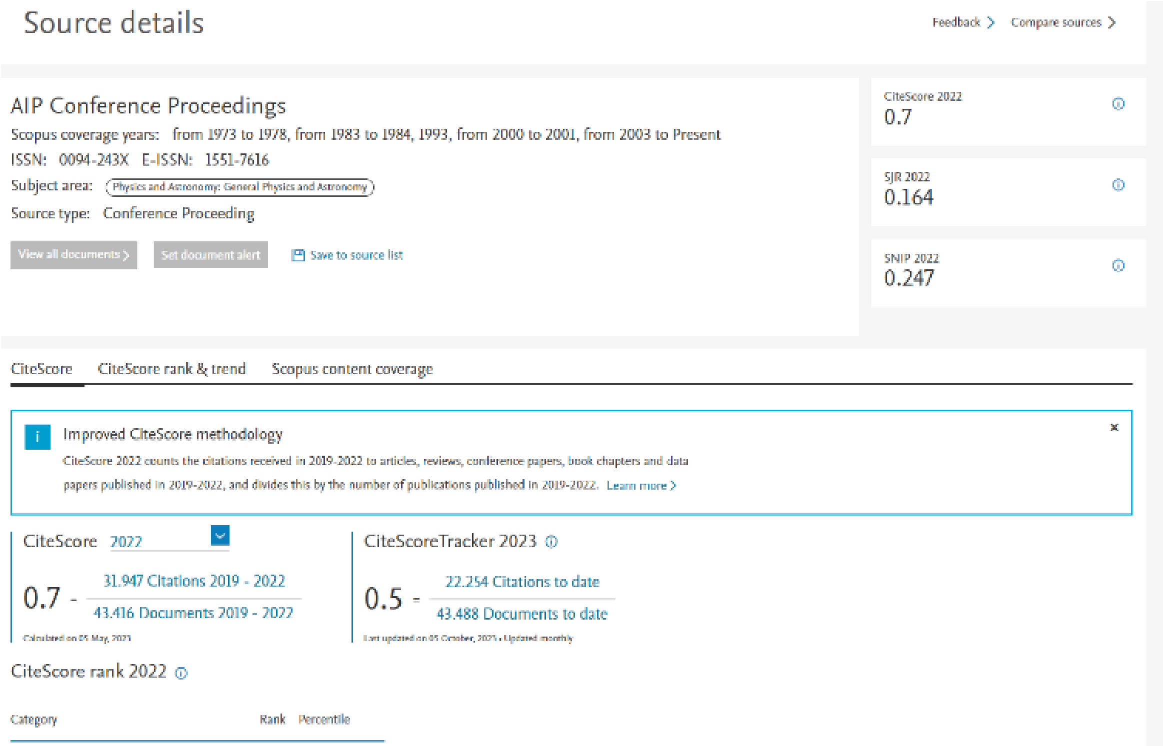

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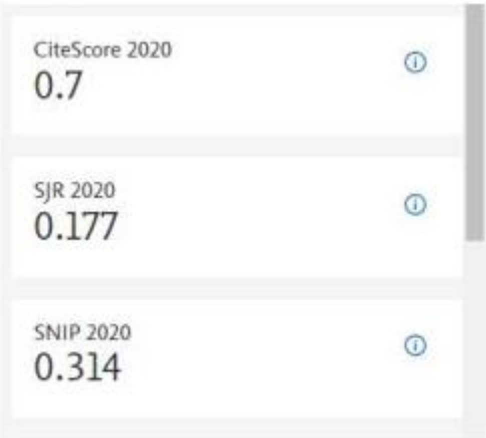

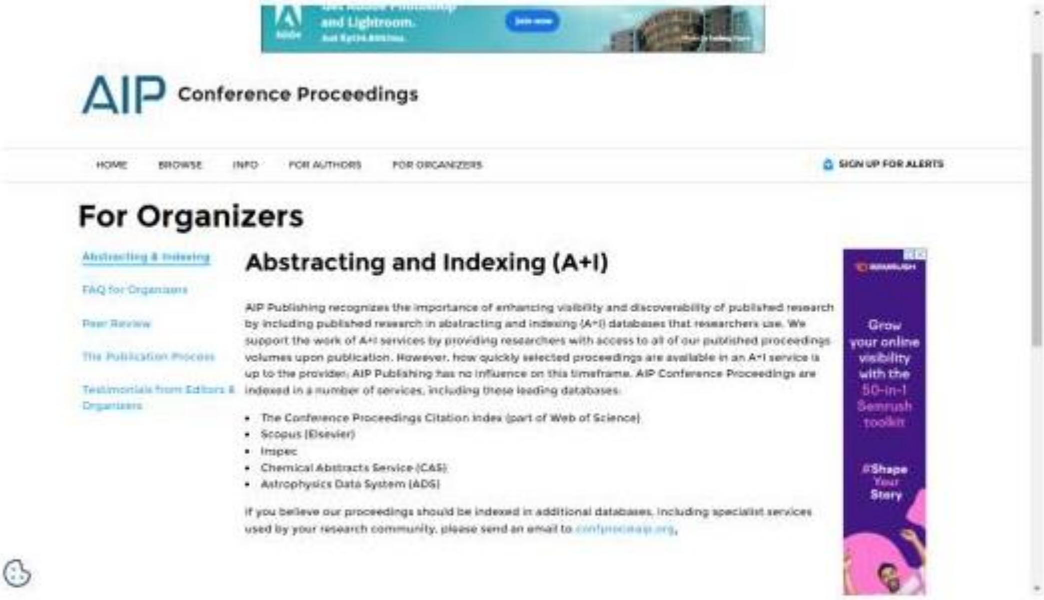

Multi-Layer Facies Distribution of Sihapas Group in the Central Region of Central Sumatra Basin

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Abstract. The study area is situated in the central region of the Central Sumatra Basin, approximately 60 km Northwestern Pekanbaru. Since the 1970s, the Central Sumatra Basin is one of the largest hydrocarbon producers. The Sihapas Group has been a multi-layer productive reservoir in this area, especially in Bangko and Bekasap Formation. These formations are composed of up to 500 ft sediment thickness then superimposed by Telisa and Petani Formation. The previous study has been recognized that the Sihapas Group was deposited during the transgressive phase, Early Miocene - Middle Miocene in age. This transgressive phase has provided a thickening-up succession of shale. Specifically, in this area, the Sihapas Group (Bangko and Bekasap Formation) were deposited in the estuarine tidal system. Based on 3 wells core description and bricket biostratigraphy, Channel, bar, and tidal flat facies are significantly developed. The vertical facies distribution is identified by core description within well and by electrofacies in the un-core interval. The spatial facies distribution was determined using a pie-chart discrete log from almost entirely wells and sweetness seismic attribute. They have appropriate to the regional paleogeography of Sihapas Group from northeast to southwest. This research purpose is to identify the facies spatial distribution of each reservoir zone in the Sihapas Group. Subsequently, this study will be very useful for guide the properties lateral distribution.

Keywords : Central Sumatra Basin, facies distribution, Sihapas Group, sweetness attribute

INTRODUCTION

The study area is situated in the central region of Rokan belongs to Central Sumatra Basin, approximately 60 km southeastern Duri Field and 60 km northwestern Pekanbaru (Figure 1). The tectonic setting of Central Sumatra basin divided into 3 tectonic episodic: F1 (50-26Ma), F2 (26-13 Ma), F3 (13 Ma-recent) [1]. F1 (syn-rift phase) is an extensional syn-rift regime during Eocene-Oligocene, F2 (post-rift phase) is a basin sagging regime in the Early-Middle Miocene, and F3 (uplifting and inversion phase) is a compressional regime in the Late Miocene-recent. The Central Sumatra Basin consists of Early Tertiary sediments (Eocene-Oligocene) succession overlying complex pre-Tertiary metamorphic and igneous lithology, it is bounded by the Barisan Mountains on the western, Malaysian Shield on the eastern, and Asahan arc on the northern [2]. This basin early formed half-graben structures were filled with terrestrial and lacustrine deposits [3]. This study area is a horst block complex that is bounded by two major faults in the eastern existing anticline. In a regional sense, the Sihapas Group consisting of the Menggala, Bangko, Bekasap, and Duri Formation were deposited in the transgressive sedimentary package [4]. Despite early stages of Sihapas Group may also be syn-rift, for the most of this accumulation as the sediments were transported southeastward from locally up-lifted areas onto a gradually subsiding shallow shelf [5]. The Lower Sihapas Group was deposited unconformably over the Pematang Group that marking by the Menggala Formation deposition. The Menggala Formation is characterized by fine to coarse-grained sandstone with pebbles conglomerates, local tuffaceous and coal horizons, and fluvial to deltaic shale [6]. The Bekasap and Bangko Formation are generally characterized by a thinning-upward sandstone in a shallow marine environment. The reservoirs in the Sihapas Group contain a variety of facies, including pebble conglomerate beds, well-preserved stratification sandstone, intensely bioturbated, open marine trace fossil, and glaucony-bearing sandstone [3;7;8].

Facies modeling forms an integral part of geological modeling, result from complex geological processes. it is characterized by considerable amounts of heterogeneity in its spatial distribution [9]. In reservoir characterization, facies modeling is the important one to determine the spatial variability of properties. Stochastic methods are a standard of mathematical geology for reservoir characterization worldwide [10]. The Kriging method is one of the mathematically advanced deterministic interpolation methods. The geostatistical algorithm is the one of conditional simulation approach that is defined as a geostatistical method that used to predict unknown data sets which have the same variability as the original data [11]. Kriging is a statistical method based on estimation technique that was first suggested by Matheron in 1963.

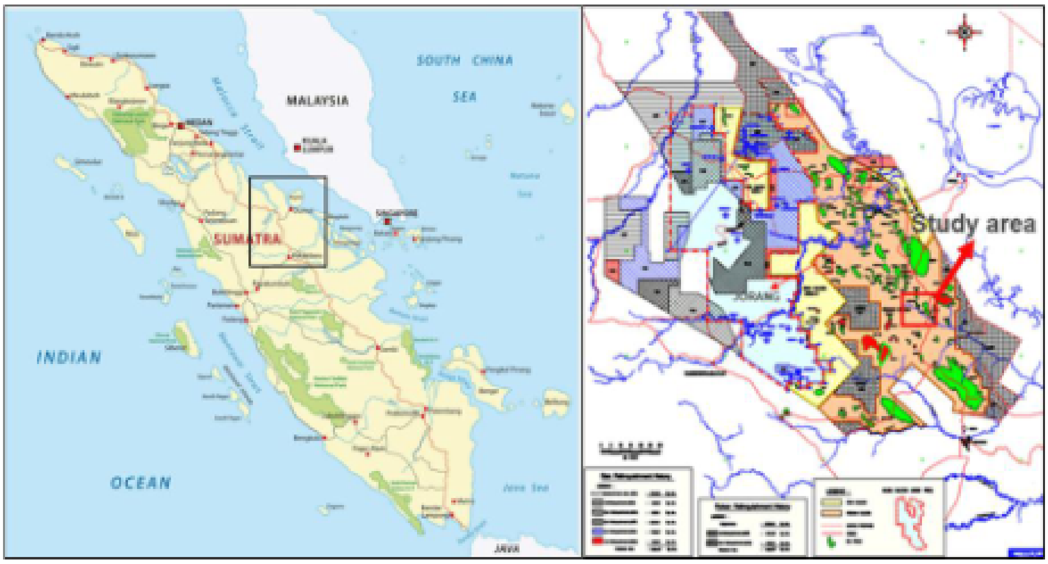

FIGURE 1. Location of the study area in the Central Sumatra Basin

DATA AND METHOD

Some data were used for analysis are subsurface data consists of geophysical well log data, 3D seismic, core image, core description, and previous study. The structural and stratigraphic evaluation was based on a variety of data that are listed below:

a. Geophysical well log data: well logs were used for electrofacies analysis from gamma-ray, resistivity, neutron and density. Some of these wells did not have gamma-ray, neutron, and density. However, these wells can be identified facies in the un-core interval. If the discrete facies has been done, it was up-scaled to the grid model for the 3D facies modeling using the geostatistical method.
b. Core data and core description: depositional environment was identified based on 5 wells that have core description. Biostratigraphic and core description data has been inferred that paleobathymetry change from Inner neritic-outer neritic.

c. Seismic attribute (sweetness): sweetness attribute has often been mentioned as an approach to local oil and gas enriching areas in sedimentary strata. Furthermore, this attribute was used as soft data to lateral facies distribution.

RESULT AND DISCUSSION

The research area belongs to the Central Sumatra Basin, in the North Aman Sub-basin. The South Aman through is a north-south trending half-graben, it was formed during the Eocene-Oligocene Rifting [12]. According to many previous studies in the South Aman Through, the sediment in this sub-basin has been filled with terrestrial sediments and shallow marine sediments. The Sihapas group consists of Menggala, Bangko, Bekasap, and Duri Formation. The Menggala Formation is the older Sihapas Group which is the basal transgressive deposit. It consists of conglomeratic sandstones, which gradually fine to medium-grained sandstones. This sediment was deposited during the Late Oligocene to Early Miocene. The Bangko Formation conformably overlies and interfingers partially with Menggala Formation. It was composed of calcareous shale gradually fine to medium sandstone interbeds and deposited during Late Oligocene to Early Miocene in age. The Duri Formation conformably overlies and partly interfingers with the Bekasap Formation. It is composed of interbedded fine to medium-grained sandstone and shale, which were deposited during the Early Miocene. The Duri Formation conformably overlies and partly interfingers with the Bekasap Formation. It is composed of interbedded fine to medium-grained sandstone and shale. Its age is Early Miocene.

This study was analyzed using 5 wells that have biostratigraphy, core description, and slice sweetness attribute. The biostratigraphy was analyze based on 2 wells for depositional environment identification. Well-A revealed that Bangko Formation is the oldest Formation of the Sihapas Group in this area. It was deposited during N4 to the lower part of N5 ("Early" Early Miocene). The Bekasap Formation conformably overlies Bangko Formation. it was deposited during lower part of N5 (Early Miocene). Based on the presence of planktic and nanno, Bangko Formation predominantly inner tidal sediment and gradually deepening up to the Bekasap Formation. Well-B revealed that Bangko and Bekasap Formation were deposited during the Early Miocene. They were deposited in the inner neritic environment (Figure 2).

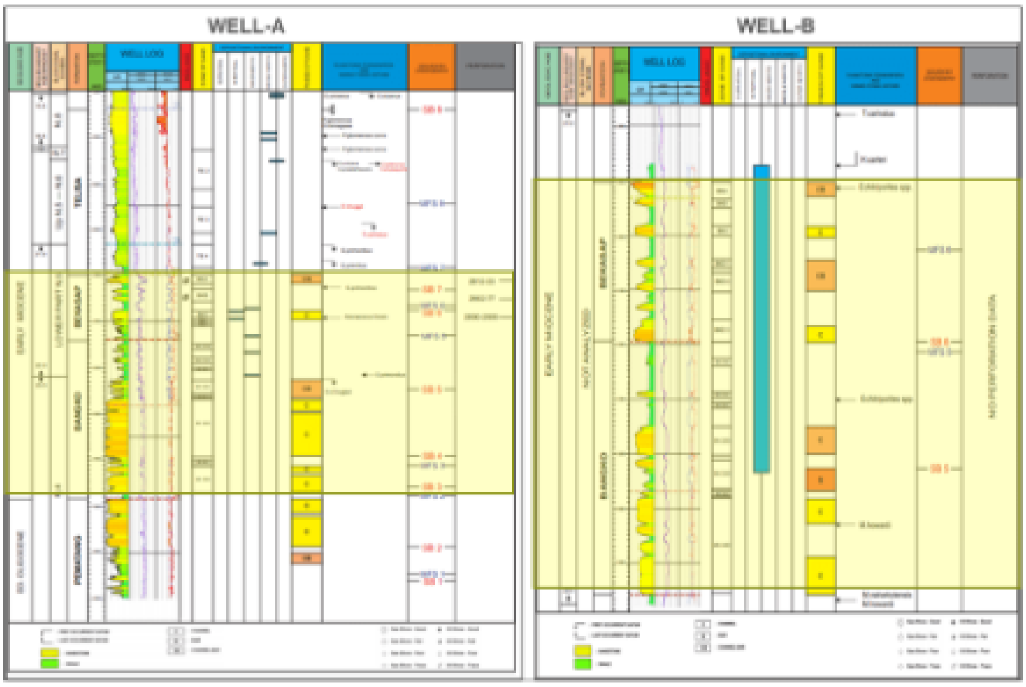

FIGURE 2. Biostratigraphic data in Well-A and Well-B; Well-A) Showing the Bangko and Bekasap Formation was deposited during Early Miocene in inner tidal to inner neritic; Well-B) showing the Bangko and Bekasap Formation was deposited during Early Miocene in Inner neritic.

Based on 3 wells in this area (Well-C, Well-D, and Well-E), are concluded transgressive phase occurs in the Bangko to Telisa Formation. Well-C has 3 core intervals, interval 2799-2825' ft, interval 2850-2882' ft, and interval 2888-2905' ft (Figure 3). Core interval 2799-2825' ft in the Well-C shows light brown oil-stained, greenish glauconite sandstones (sublitharenite), fine-medium grain, poor-moderate sorted, and angular-subrounded. Based on core data and supported by well log pattern, this interval was concluded mouth bar and shelf depositional system. The thickness of these facies is approximately 26 feet. Core interval 2850-2882' ft shows light brown oil-stained, greenish, fine to very coarse-grained bioturbated sandstone with some granules and pebbles (conglomeratic sandstone), cross-bed and wavy sedimentary structures, poor-moderate sorted, angular-subrounded. The classification of sandstones is sublitharenite, litharenite, and subarkose. Based on core data and supported by well log pattern, this interval was concluded estuarine channel, tidal sand bar, and tidal sand flat. The thickness of these facies is approximately 32 feet. Core intervals 2888-2905' ft shows two amalgamated successions. The upper part is composed of interbedded sandstone and shale with fine to medium-grained, moderate to well-sorted, angular to sub-angular. This part thickness is 4.6 feet. The lower part reveals a coarsening upward which consists of low to moderately bioturbated sandstone and fine to medium-grained at the base. This interval was concluded regressive shoreface, tidal, and estuarine tidal fill facies. This part thickness is 20 feet.

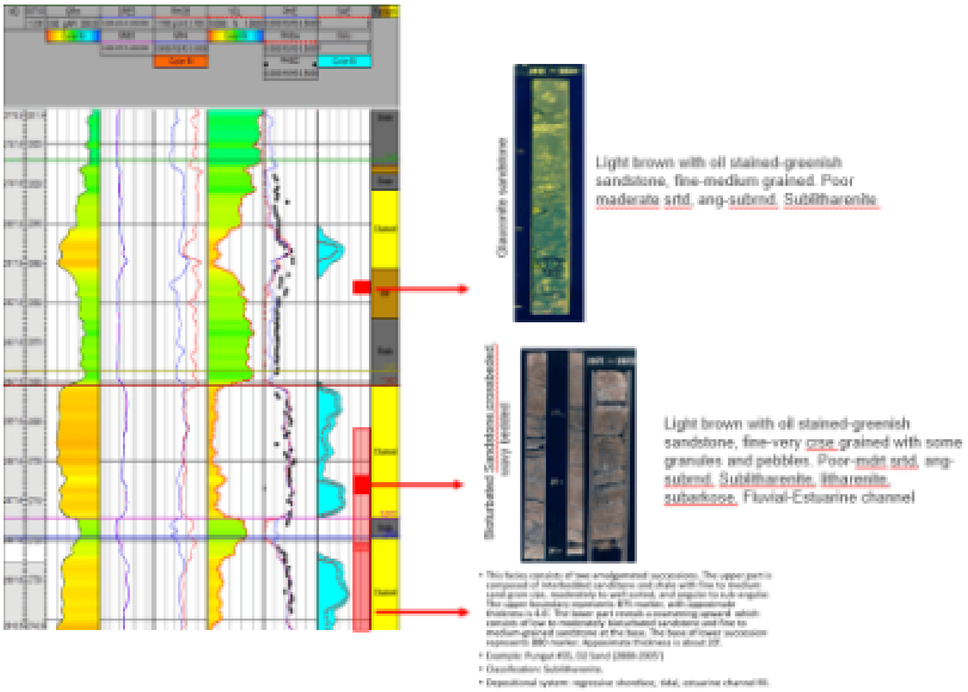

FIGURE 3. Core intervals in Well-C, interval 2799-2825', interval 2850-2882', and interval 2888-2905'

Well-D have 2 core intervals, interval 2730-2804' and 2804-2827'ft. Core interval 2730-2804' shows light brown oil-stained and whity brown sandstone, fine to coarse-grained containing granules and pebbles at some level, moderate to well-sorted, and sub-angular to sub-rounded. Two similar facies associations were stack in the form of a multistory succession of 76 feet blocky-shape gamma-ray. The upper boundary is also in sharp contact with overlying bioturbated shaly siltstone. This interval consists of an estuarine channel, tidal sand bar, and tidal channel. Core interval 2804-2827 are equivalent with Bekasap Formation shows light brown oil-stained cross-bedded sandstones, through and planar, medium to coarsely grained with some granules and pebbles, poorly to moderately sorted, angular to rounded. Based on core data and supported by well log pattern, this interval was concluded tidal sand bar and 23 ft in thickness (Figure 4).

Well-E have 3 core intervals, interval 2856-2896', interval 2997-3015', and interval 3041-3087'. Core interval 2856-2896' shows light brown oil-stained to gray wavy-bedded sandstones, fine-grained sandstone, coarser at top and more clay at the lower interval, moderate to poorly-sorted, sub-angular to sub-rounded. Core interval 2997-3015' shows light brown oil-stained, medium to coarse cross-bedded sandstone, moderate to well-sorted, sub-angular to sub-rounded, planar, tabular, through cross-stratification, calcite cement on the bottom, and contact with shale. This interval was concluded an estuarine channel and 33'ft in thickness. Core interval 3041-3087' shows light brown oil-stained, very fine to fine-grained wavy bedded sandstones, fining upward, moderately to well-sorted, sub-angular to sub-rounded, rhythmic alternation of wavy mud drapes laminae, local cross-beds, flaser, and slightly bioturbation. This core interval was concluded tidal sand flat or channel (Figure 5).

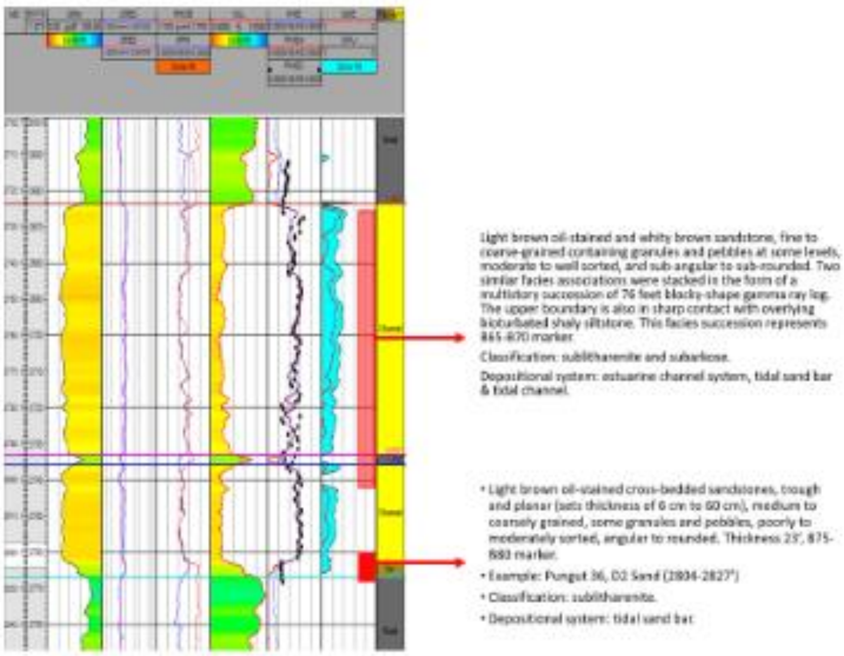

FIGURE 4. Core intervals in Well-D, interval 2730-2804' and interval 2804-2827

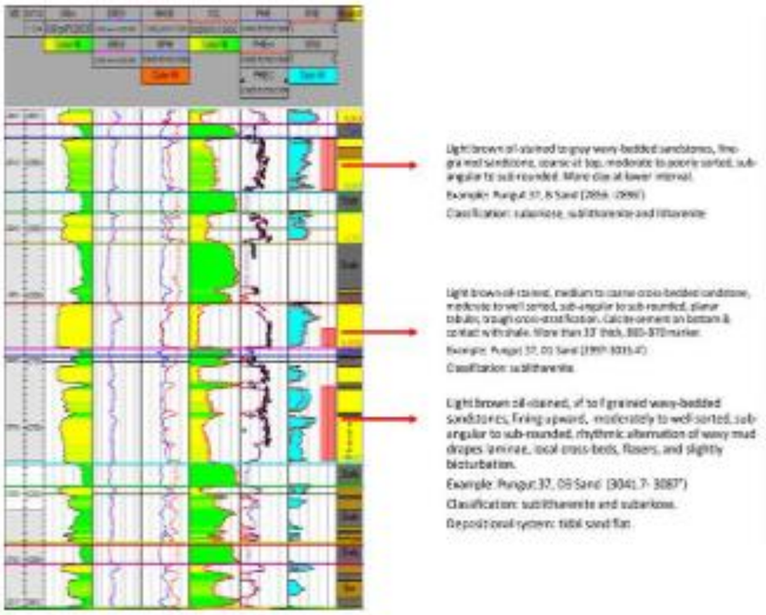

FIGURE 5. Core intervals in Well-E, interval 2856-2896', interval 2997-3015', and interval 3041-3087'

Based on well by well facies correlation has been analyzed, the Sihapas Group becoming shallow marine deposit to the SW (Figure 6). The facies correlation was in the same direction as sedimentation that formed thick sediment in the Northeast of the basin. The well log pattern is predominantly terrestrial sediment in NE, and gradually changes becoming Outer neritic sediment to the SW. The Sihapas Group is the thickening bed in the NE of the basin that is shallower than the thinner bed in the SW. The subsurface model on the basin architecture shows that the basin is getting deeper in the SW part of the basin.

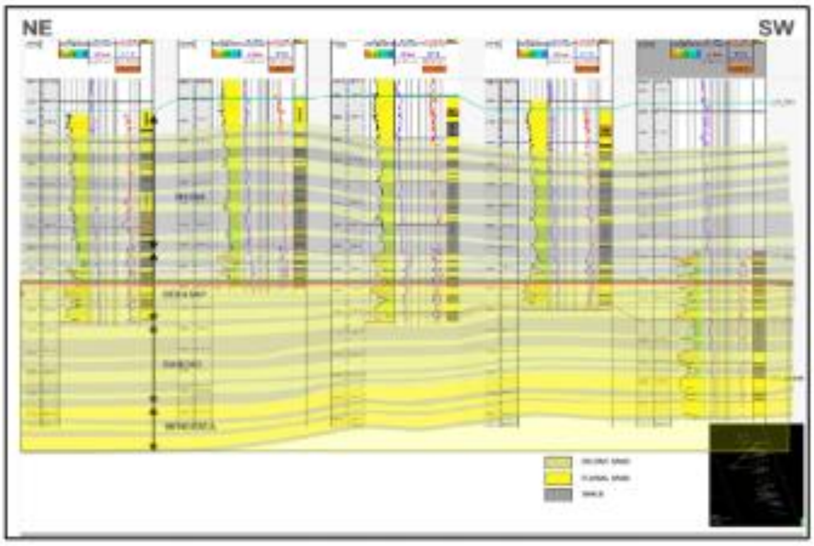

FIGURE 6. Stratigraphic correlation NE-SW, shows depositional direction is NE to SW

The next method to build the facies distribution is generating a facies pie-chart from each well. It was integrated by sweetness attribute as soft data to guidance lateral distribution (Figure 7). The high sweetness is representing sandy and hydrocarbon interval. Each slice from the reservoir zone was extracted to obtain channel and bar geometry and probability map.

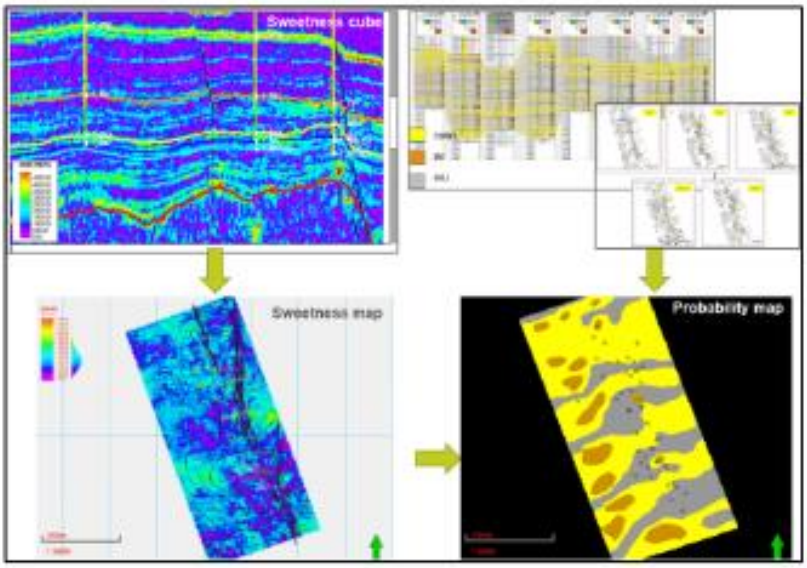

FIGURE 7. Integrating well log and sweetness attribute to generate a facies probability map

Based on the sweetness map, bright spots were showing the sandstone facies (channel or bar). The facies distribution was generated using log data up-scale with sweetness as horizontal trending. The anisotropy direction can be identified using several variograms calculation and determine the maximum and minimum continuity ranges or it is possible to find the anisotropy general trend as the direction at which the variogram map is elongated. The maximum and continuity ranges were obtained from the depositional regional direction which is revealed heterogeneity and homogeneity depositional system. The modern-day river in Riau can explain how long and how wide they channel and bar as a subsurface analog (Figure 8). Based on the whole facies model, the channel length ranges 2 to 2.5 km and the channel width ranges 0.4 to 2.3 km. This is also compared to the modern-day channel length and width (Kampar River and Kuantan Indragiri River. Wherein, both Kampar river and Kuantan Indragiri river have 61 km length and 3.7 to 4 km width.

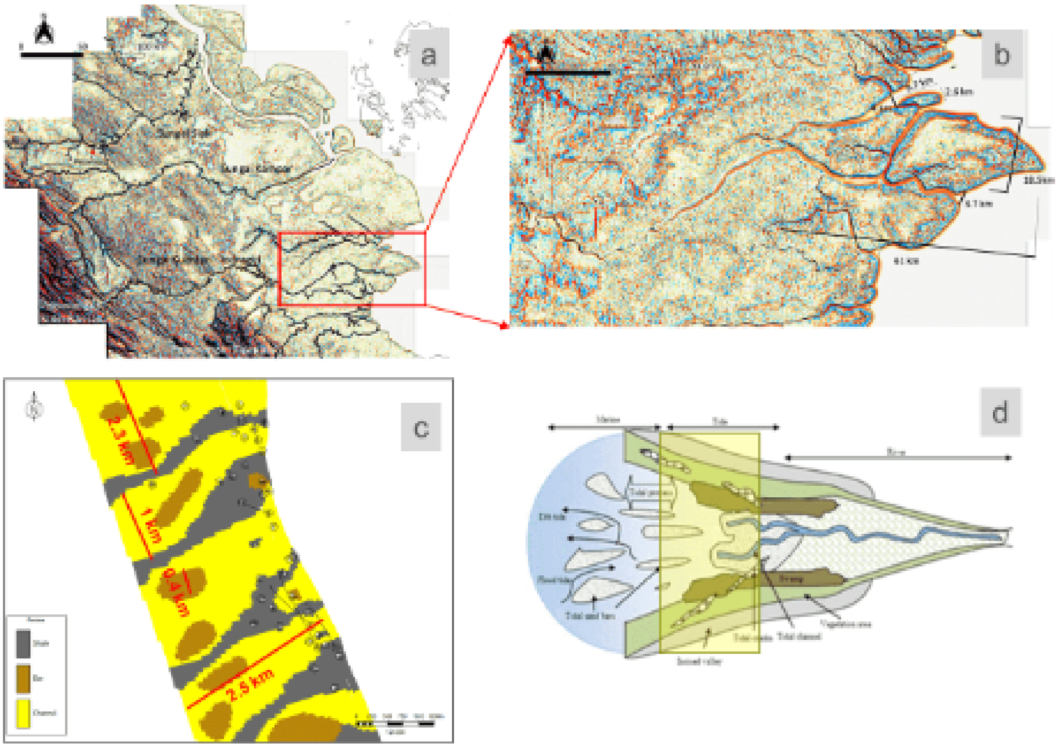

FIGURE 8. a) Modern-day river; b) modern-day river zoom in; c) subsurface facies geometry; d) facies geometry model

To normalize a non-normal distribution was used a software that has an algorithm that can change any distribution been normal. The TGS is the suitable modeling method to normally data distributing and stationary. The maximum and minimum anisotropy direction, ranges, and variogram characteristics in the anisotropy direction are the essential parameters to generate a property model. If the well distribution is sporadic, a tolerance angle should be encountered in the calculation [13]. To determine maximum and minimum continuity anisotropy direction was needed the same procedures were as the facies data determination. The anisotropy direction which is the elongation direction map could be easily determined using a variogram map. The lag distance within the disorganized well distribution should be the average spacing between wells. In this case, the lag distance is 250 m, which was chosen to be the best to reveal the structural extend. Besides that, the tolerance distance equal to the half lag distance is the best choice for regular and irregular well lag spacing distribution. The lags number is 8 was chosen to cover this study. The major direction is N55E and the minor direction is N325W (Figure 9). The facies geostatistical modeling is generate using the Truncated Gaussian Simulation method. The model results have been shown that TGS tends to create a smoother distribution of the variables, whereas conditional simulation tends to represent more details as in actual data (Figure 10). The final geostatistical modeling using both the TGS and conditional simulation was validated with actual well log data using cross-validation methods.

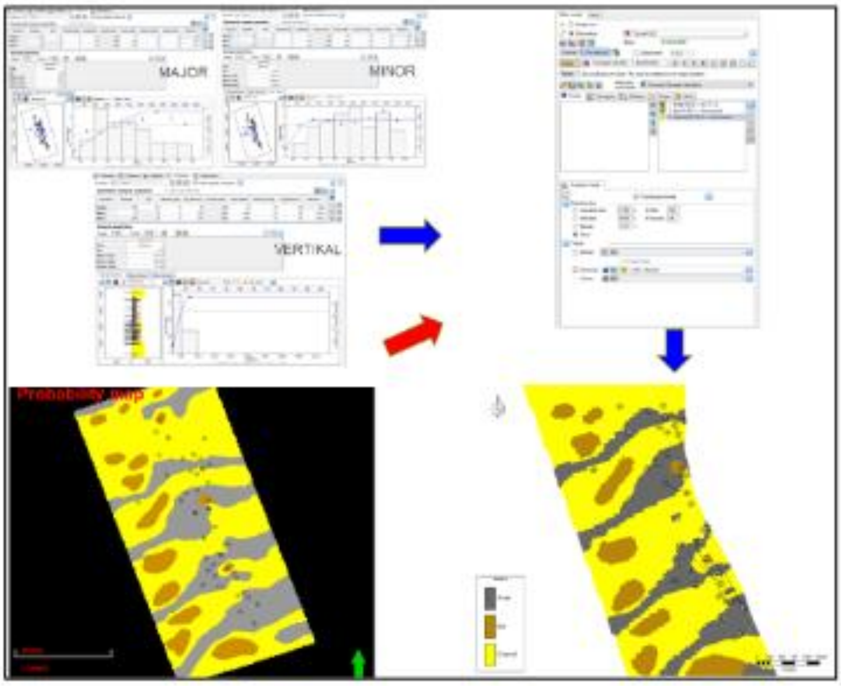

FIGURE 9. TGS geostatistical facies modeling

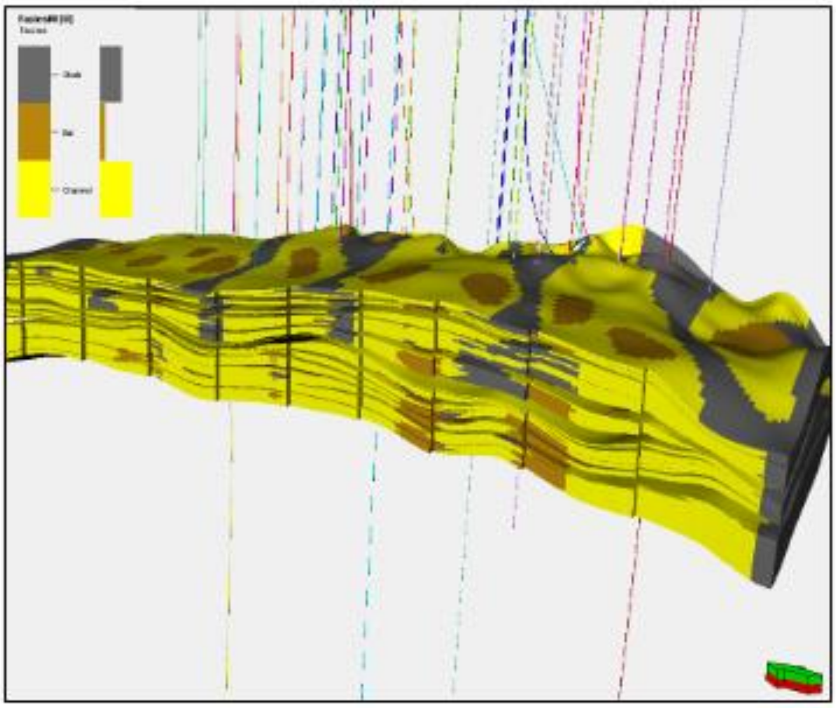

FIGURE 10. Multi-layer Facies distribution based on TGS modeling

CONCLUSION

Several conclusions drawn from this study are listed below:

- Facies was analyzed using 5 wells core description, the pattern of well-log, and sweetness attribute revealed that this area is 3 facies (channel, bar, and shale) within the fluvial-estuarine depositional system.
- Facies correlation was in the same direction as sedimentation that formed thick sediment in the Northeast of the basin. The well log pattern predominantly terrestrial sediment in NE, and gradually changes becoming Outer neritic sediment to the SW.
- The spatial analyses have been suggesting that the facies variograms are best represented by the simple spherical theoretical model. The geostatistical modeling of facies is done using the Truncated Gaussian Simulation method. The lag distance for the sporadic well distribution should be the average spacing between wells. In the current study, a lag distance of 250 meters. The major direction is N55E and the minor direction of continuity is N325W.
- The facies model has been compared with the modern-day channel, the channel model length ranges 2 to 2.5 km, and the channel model width ranges 0.4 to 2.3 km. If compared to the modern-day channel both Kampar river and Kuantan Indragiri river have 61 km length and 3.7 to 4 km width.

ACKNOWLEDGMENTS

The authors wants to thank Pertamina Hulu Rokan and "Badan Afiliasi Teknologi Mineral Universitas Trisakti" for providing the data useful in this research.

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CEK KESAMAAN

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Abstract. The Study area is situated in the central region of the Central Sumatra Basin, approximately 60 km Northwestern Pekanbaru. Since the 1970's, Central Sumatra Basin is the one of the largest hydrocarbon producers. The Sihapas Group has been multi-layer productive reservoir in this area, especially in Bangko and Bekasap Formation. These formations are composed of up to 500 ft sediment thickness then superimposed by Telisa and Petani Formation. The previous study has been recognized that Sihapas Group was deposited during the transgressive phase, Early Miocene - Middle Miocene in age. This transgressive phase has provided thickening-up succession of shale. Specifically, in this area, the Sihapas Group (Bangko and Bekasap Formation) were deposited in the estuarine tidal system. Based on 3 wells core description and bricket biostratigraphy, Channel, bar, and tidal flat facies are significantly developed. The vertical facies distribution is identified by core description within well and by electrofacies in the un-core interval. The spatial facies distribution was determined using pie-chart discrete log from almost entirely wells and sweetness seismic attribute. They have appropriate to the regional paleogeography of Sihapas Group from northeast to southwest. The main objective of this study is an analysis of the spatial behavior of the Facies. Subsequently, this study will be very useful for guide the properties lateral distribution.

Keywords : Central Sumatra Basin, Sihapas Group, facies distribution, sweetness attribute

INTRODUCTION

The study area is situated in the central region of Rokan Block Central Sumatra Basin, approximately 60 km southeastern Duri Field and 60 km northwestern Pekanbaru (Figure 1). The tectonic setting of Central Sumatra basin divided into 3 tectonic episodic: F1 (50-26Ma), F2 (26-13 Ma), F3 (13 Ma-recent) [1]. F1 (syn-rift phase) is an extensional syn-rift regime during Eocene-Oligocene, F2 (post-rift phase) is a basin sagging regime in the Early-Middle Miocene, and F3 (uplifting and inversion phase) is a compressional regime in the Late Miocene-recent. The Central Sumatra Basin consists of Early Tertiary sediments (Eocene-Oligocene) succession overlying complex pre-Tertiary metamorphic and igneous lithology, it is bounded by the Barisan Mountains on the western, Malaysian Shield on the eastern, and Asahan arc on the northern [2]. These early formed half-graben structures were filled with terrestrial and lacustrine deposits [3]. This study area is a horst block complex that is bounded by two major faults in the eastern existing anticline. In a regional sense, the Sihapas Group consisting of the Menggala, Bangko, Bekasap, and Duri Formation were deposited in the transgressive sedimentary package [4]. Despite early stages of Sihapas Group may also be syn-rift, for the most part of this accumulation as the sediments were transported southeastward from locally up-lifted areas onto a gradually subsiding shallow shelf [5]. The Lower Sihapas Group was deposited unconformably over the Pematang Group that marking by the Menggala Formation deposition. The Menggala Formation is characterized by fine to course-grained sandstone with pebbles conglomerates, local tuffaceous and coal horizons, and fluvial to deltaic shale [6]. The Bekasap and Bangko Formation are generally characterized by a thinning-upward sandstone in a shallow marine environment. The reservoirs in the Sihapas Group contain a variety of facies, including pebble conglomerate beds, well-preserved stratification sandstone, intensely bioturbated, open marine trace fossil, and glaucony-bearing sandstone [3;7;8].

Facies modeling forms an integral part of geological modeling, result from complex geological processes. it is characterized by considerable amounts of heterogeneity in their spatial distribution [9]. In reservoir characterization, facies modeling is the important one to determine the spatial variability of properties. Stochastic methods are a standard of mathematical geology for reservoir characterization worldwide [10]. The Kriging method is one of the mathematically advanced deterministic interpolation methods. One of the geostatistical simulation algorithms is the conditional simulation approach which is defined as a geostatistical method used to create unknown data sets which have the same variability as the original data [11]. Kriging is a statistically based estimation technique that was initially introduced by Matheron (1963).

FIGURE 1. Location of the study area in the Central Sumatra Basin

DATA AND METHOD

Some data were used for analysis are subsurface data consists of geophysical well log data, 3D seismic, core image, core description, and previous study. The structural and stratigraphic evaluation was based on a variety of data that are listed below:

a. Geophysical well log data: well logs were used for electrofacies analysis from gamma-ray, resistivity, neutron and density. Some of these wells did not have gamma-ray, neutron, and density. However, these wells can be identified facies in the un-core interval. If the discrete facies has been done, it was up-scaled to the grid model for the 3D facies modeling using the geostatistical method.
b. Core data and core description: depositional environment was identified based on 5 wells which have core description. Biostratigraphic and core description data has been inferred that paleobathymetry change from Inner neritic-outer neritic.

c. Seismic attribute (sweetness): sweetness attribute has often been mentioned as an approach to local oil and gas enriching areas in sedimentary strata. Furthermore, this attribute was used as soft data to lateral facies distribution.

RESULT AND DISCUSSION

The research area belongs to the Central Sumatra Basin, in the North Aman Sub-basin. The South Aman through is a north-south trending half-graben, it was formed during the Eocene-Oligocene Rifting [12]. According to many previous studies in the South Aman Through, the sediment in this sub-basin has been filled with terrestrial sediments and shallow marine sediments. The Sihapas group consists of Menggala, Bangko, Bekasap, and Duri Formation. Menggala Formation is the older Sihapas Group which is the basal transgressive deposit. It consists of conglomeratic sandstones, which gradually fine to medium-grained sandstones. This sediment was deposited during the Late Oligocene to Early Miocene. The Bangko Formation conformably overlies and interfingers partially with Menggala Formation. It was composed of calcareous shale gradually fine to medium sandstones interbeds and deposited during Late oligocene to Early Miocene in age. The Duri Formation conformably overlies and partly interfingers with the Bekasap Formation. It is composed of interbedded fine to medium-grained sandstone and shale, which was deposited during the Early Miocene. The Duri Formation conformably overlies and partly interfingers with the Bekasap Formation. It is composed of interbedded fine to medium-grained sandstone and shale. Its age is Early Miocene.

This study was analyzed using 5 wells that have biostratigraphy, core description, and slice sweetness attribute. Biostratigraphic analysis based on 2 wells for depositional environment identification. Well-A revealed that Bangko Formation is the oldest Formation of the Sihapas Group in this area. It was deposited during N4 to the lower part of N5 ("Early" Early Miocene). The Bekasap Formation conformably overlies Bangko Formation. it was deposited during lower part of N5 (Early Miocene). Based on the presence of planktic and nanno, Bangko Formation predominantly inner tidal sediment and gradually deepening up to the Bekasap Formation. Well-B revealed that Bangko and Bekasap Formation were deposited during the Early Miocene. They were deposited in inner neritic environment (Figure 2).

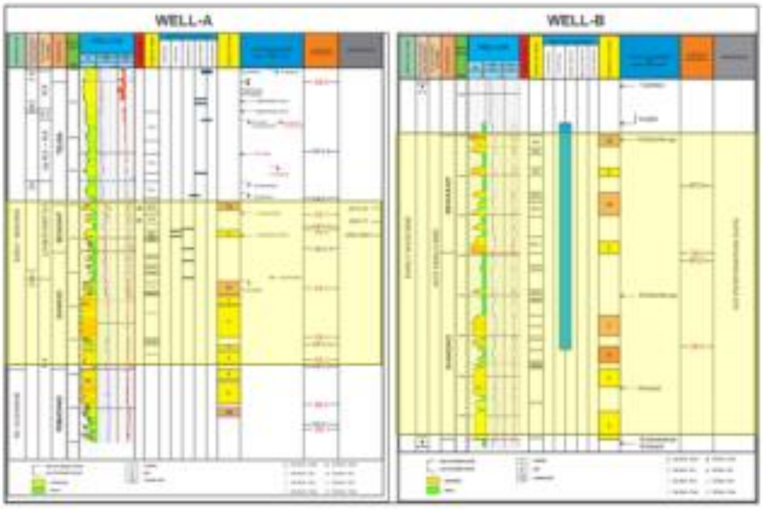

FIGURE 2. Biostratigraphic data in Well-A and Well-B; Well-A) Showing the Bangko and Bekasap Formation was deposited during Early Miocene in inner tidal to inner neritic; Well-B) showing the Bangko and Bekasap Formation was deposited during Early Miocene in Inner neritic.

Based on 3 wells in this area (Well-C, Well-D, and Well-E), are concluded transgressive phase occurs in the Bangko to Telisa Formation. Well-C has 3 core intervals, interval 2799-2825' ft, interval 2850-2882' ft, and interval 2888-2905' ft (Figure 3). Core interval 2799-2825' ft in the Well-C shows light brown oil-stained, greenish glauconite sandstones (sublitharenite), fine-medium grain, poor-moderate sorted, and angular-subrounded. Based on core data and supported by well log pattern, this interval was concluded mouth bar and shelf depositional system. The thickness of these facies is approximately 26 foot. Core interval 2850-2882' ft shows light brown oil-stained, greenish, fine-very coarse-grained bioturbated sandstone with some granules and pebbles (conglomeratic sandstone), cross-bed and wavy sedimentary structures, poor-moderate sorted, angular-subrounded. The classification of sandstones is sublitharenite, litharenite, and subarkose. Based on core data and supporting by well log pattern, this interval was concluded estuarine channel, tidal sand bar and tidal sand flat. The thickness of these facies is approximately 32 foot. Core interval 2888-2905' ft shows two amalgamated successions. The upper part is composed of interbedded sandstone and shale with fine to medium-grained, moderate to well-sorted, angular to sub-angular. This part thickness is 4.6 foot. The lower part reveals a coarsening upward which consists of low to moderately bioturbated sandstone and fine to medium grained at the base. This interval was concluded regressive shoreface, tidal, and estuarine tidal fill. This part thickness is 20 feett.

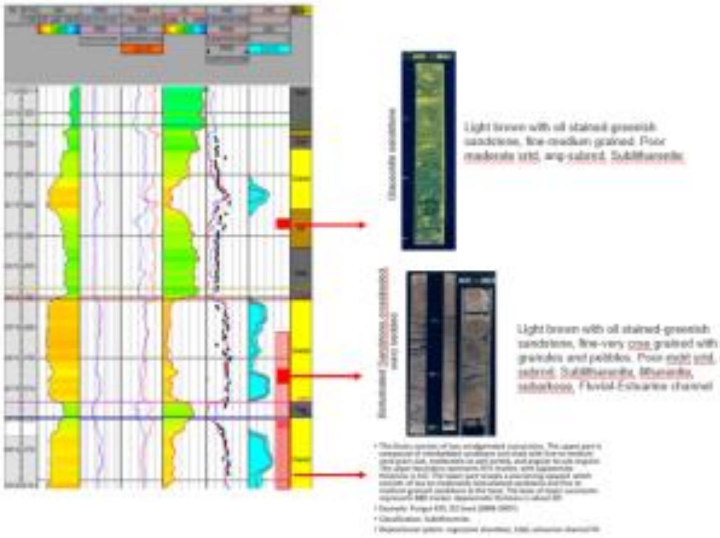

FIGURE 3. Core intervals in Well-C, interval 2799-2825', interval 2850-2882', and interval 2888-2905'

Well-D have 2 core intervals, interval 2730-2804' and 2804-2827'ft. Core interval 2730-2804' shows light brown oil-stained and whity brown sandstone, fine to coarse-grained containing granules and pebbles at some level, moderate-well sorted, and sub-angular to sub-rounded. Two similar facies associations were stack in the form of a multistory succession of 76 foot blocky-shape gamma ray. The upper boundary is also in sharp contact with overlying bioturbated shaly siltstone. This interval consists of estuarine channel, tidal sand bar, and tidal channel. Core interval 2804-2827 are equivalent with Bekasap Formation shows light brown oil-stained cross-bedded sandstones, through and planar, medium to coarsely grained with some granules and pebbles, poorly to moderately sorted, angular to rounded. Based on core data and supported by well log pattern, this interval was concluded tidal sand bar and 23 ft in thickness (Figure 4).

Well-E have 3 core intervals, interval 2856-2896', interval 2997-3015', and interval 3041-3087'. Core interval 2856-2896' shows light brown oil-stained to gray wavy-bedded sandstones, fine-grained sandstone, coarser at top and more clay at the lower interval, moderate to poorly-sorted, sub-angular to sub-rounded. Core interval 2997-3015' shows light brown oil-stained, medium to coarse cross-bedded sandstone, moderate to well-sorted, sub-angular to sub-rounded, planar, tabular, through cross-stratification, calcite cement on bottom and contact with shale. This interval was concluded estuarine channel and 33'ft in thickness. Core interval 3041-3087' shows light brown oil-stained, very fine to fine grained wavy bedded sandstones, fining upward, moderately to well sorted, sub-angular to sub-rounded, rhythmic alternation of wavy mud drapes laminae, local cross-beds, flasers, and slightly bioturbation. This core interval was concluded tidal sand flat or channel (Figure 5).

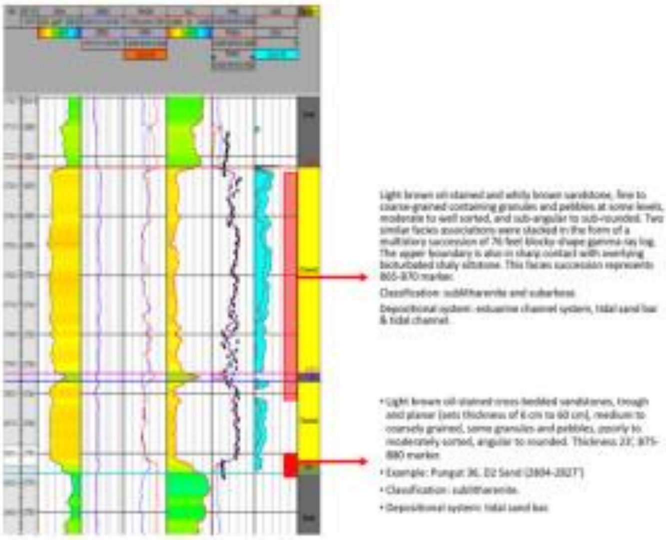

FIGURE 4. Core intervals in Well-D, interval 2730-2804' and interval 2804-2827

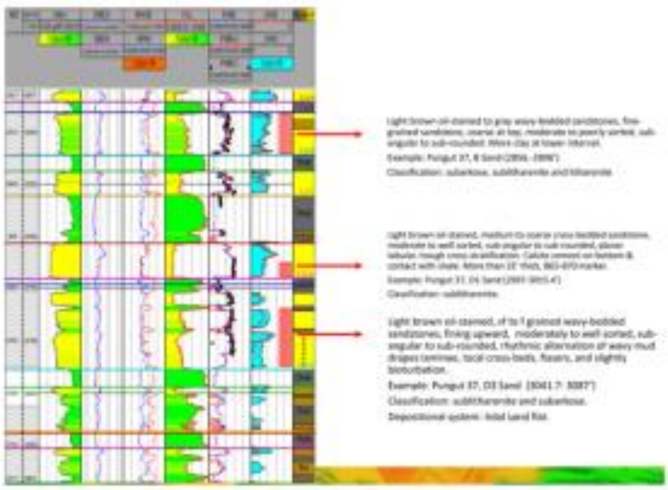

FIGURE 5. Core intervals in Well-E, interval 2856-2896', interval 2997-3015', and interval 3041-3087'

Based on well by well facies correlation has been analyzed, the Sihapas Group becoming shallow marine deposit to the SW (Figure 6). Facies correlation was in the same direction as sedimentation that formed a thick sediment in the Northeast of the basin. The well log pattern predominantly terrestrial sediment in NE, and gradually changes becoming a Outer neritic sediment to the SW. The Sihapas Group is thickening bed in the NE of the basin that is shallower than the thinner bed in the SW. The subsurface model on the basin architecture shows that the basin is getting deeper in the SW part of the basin.

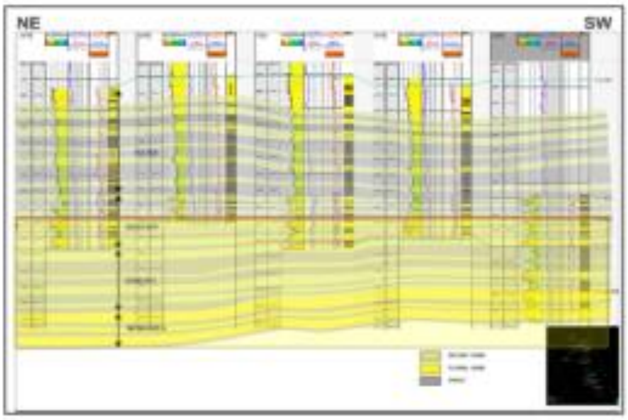

FIGURE 6. Stratigraphic correlation NE-SW, shows depositional direction is NE to SW

The next method to build the facies distribution is generating a facies pie-chart from each well. It was integrated by sweetness attribute as soft data to guidance lateral distribution (Figure 7). The high sweetness is represents sandy and hydrocarbon interval. Each slice from reservoir zone was extracted to obtain channel and bar geometry and probability map.

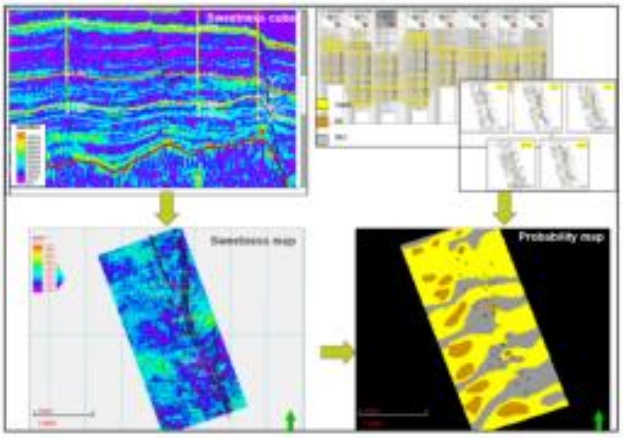

FIGURE 7. Integrating well log and sweetness attribute to generate a facies probability map

Based on the sweetness map, bright spots were showing the sandstone facies (channel or bar). The facies distribution was generated using log data up-scale with sweetness as horizontal trending, and to identify the anisotropy direction is to calculate several variograms and determine the maximum and minimum continuity ranges or it is possible to find the general trend of anisotropy is the direction at which the variogram map is elongated. The maximum and continuity ranges were obtained from the depositional regional direction which is revealed heterogeneity and homogeneity depositional system. The modern-day river in Riau can explain how long and how wide they channel and bar as a subsurface analog (Figure 8).

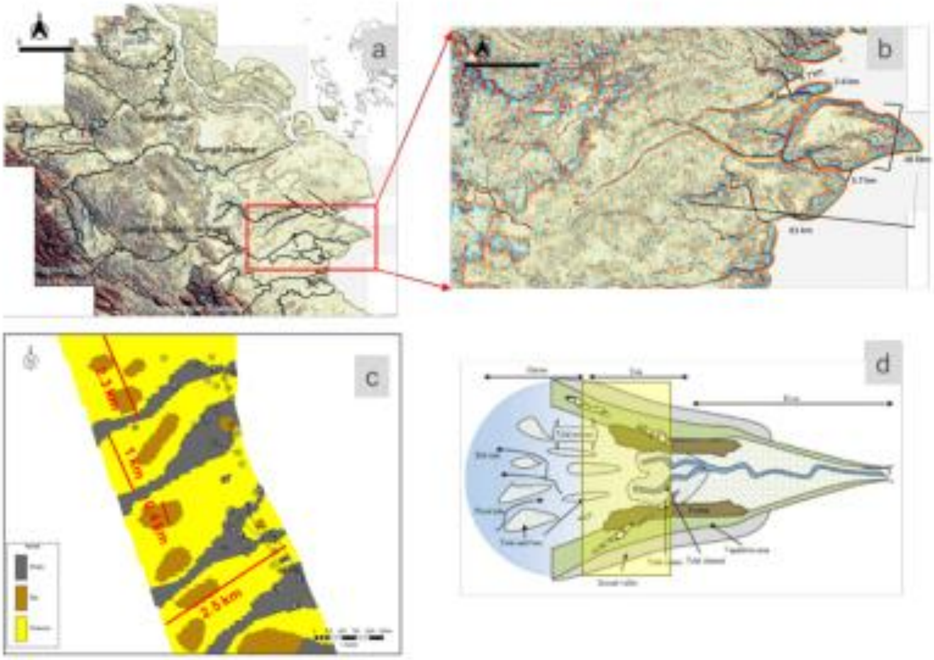

FIGURE 8. a) Modern-day river; b) modern-day river zoom in; c) subsurface facies geometry; d) facies geometry model

For making non-normally distributions normalized, this software has itself an algorithm that makes any distribution normalized. Making the data normally distributed and stationary, now it is time to do modeling with TGS. The direction of major and minor anisotropy, their ranges and variogram characteristics in major direction of anisotropy are essential parameters for producing a proper model. Because the well distribution is irregular, a tolerance angle should be encountered in the calculation [13]. For determination, the direction of anisotropy that is the direction of maximum and minimum continuity we do the same procedure as with the facies data are taken. Using a variogram map, the direction of anisotropy, which is the direction of elongation of a map, can be easily determined. The lag distance for the irregular well distribution should be the average spacing between wells. In the current study, a lag distance of 250 m, which was found to be the best to reveal the structural extend, was chosen. On the other hand, the tolerance distance of half the lag distance was the optimal choice for both regular and irregular well distribution of the lag distance. Number of lags of 8 was chosen to cover the study area. The major direction of continuity is N55E and the minor direction of continuity is N325W (Figure 9). Geostatistical modeling of facies is done using Truncated Gaussian Simulation. The results confirmed that TGS tends to produce the smoother distribution of the variables, whereas conditional simulation tends to represent more details as in actual data (Figure 10). Results of geostatistical modeling using both approaches are validated with actual well log data using cross-validation methods.

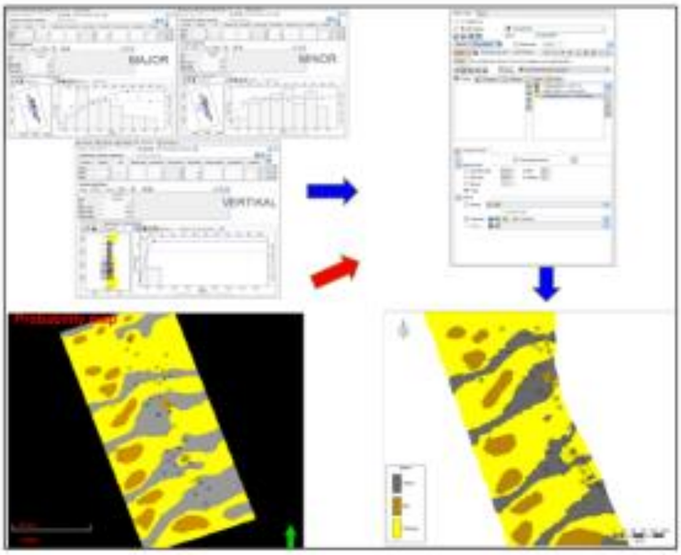

FIGURE 9. TGS geostatistical facies modeling

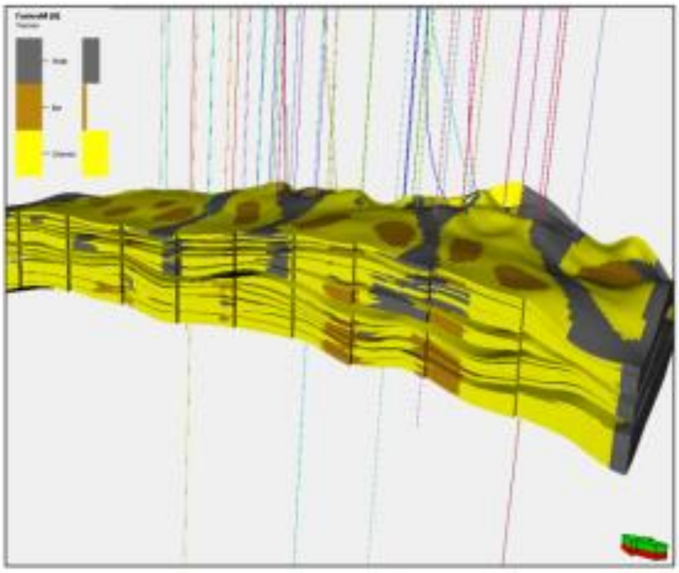

FIGURE 10. Multi-layer Facies distribution based on TGS modeling

CONCLUSION

Several conclusions drawn from this study are listed below:

- Facies was analyzed using 5 wells core description, the pattern of well-log, and sweetness attribute revealed that this area is 3 facies (channel, bar and shale) within the fluvial-estuarine depositional system.
- Facies correlation was in the same direction as sedimentation that formed a thick sediment in the Northeast of the basin. The well log pattern predominantly terrestrial sediment in NE, and gradually changes becoming Outer Neritic sediment to the SW.
- The spatial analysis reveals that facies experimental variograms are best represented by the simple spherical theoretical model. Geostatistical modeling of facies is done using Truncated Gaussian Simulation. The lag distance for the irregular well distribution should be the average spacing between wells. In the current study, a lag distance of 250 m. The major direction of continuity is N55E and the minor direction of continuity is N325W.

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