New Perspective Paleogeography of East Java Basin; Implication respond to Oil and Gas Exploration at Kujung Formation Carbonate Reservoir

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Abstract. Paleogeography is one of critical points that always less considered by explorationist in the world. Almost all of the consideration is focused on trapping mechanism. Paleogeography is guidance in understanding both of physical and chemical of rock characteristic which will correlate with its depositional environment. Integration of various geological and geophysical data such as; tectonic, structural geology, stratigraphy, lithology, and biostratigraphy will lead us to a better understanding of rock characteristics. Six paleogeographic interpretations were made consist of; Early Tertiary (P5-56-55 ma), Middle Eocene (P14-41 ma), Late Oligocene (P22-25.5 ma), Early Miocene (N7-16.5 ma), Middle Miocene (N9-14.5 ma), and Pleistocene (NN19-1.5 ma). That six paleogeographic interpretations are assumed represent the paleogeographic evolution of East Java Basin time after time. In Middle Eocene time, it would be more than hundred possibilities regarding the location where the formation deposited. This would be controlled by the existence of some local structural paleohighs and horsts which oriented NW-SE followed by their own sedimentary transportation path. With assumption that hydrocarbon generation was occurred in 15 Ma and the depth of maturation window lies on about 2,500 m depth. Therefore, the possibility of source rock maturation is high, due to almost of the clastics sediment of Ngimbang deposited into the series of grabens. The Kujung reef types simplified define and categorize into; 1) Patch Reef 2) Berrier Reef 3) Pinnacle Reef Over Isolated Reef. Kujung Carbonates were deposited in Early Miocene when regional transgression occurred. The depositional environments were dominated by shallow marine littoral-sublittoral. Generally, the reservoir quality of this Kujung Carbonate shows fair to good quality, in range 7-32% porosity, and 1-1400 mD permeability (internal SKK Migas data).

1. Background

Indonesia is the 3rd biggest hydrocarbon reserves (±3.6000 MMSTB) and East Java Basin have proven reserves oil ±550 MMSTB. As well as prospect & lead exploration potential is the 2nd biggest on Indonesia with resources estimation are ±15.000 MMBOE from 80.000 MMBOE on East Java Basin & North East Java Basin (RPS SKK Migas, 2014). Base on those data, we need more explorations to increase national hydrocarbon reserves. As first initiated exploration, paleogeography was used in understanding physical characteristic of rock. Identification of rock distribution, especially

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fine clastical sediment from Ngimbang formation functioned as hydrocarbon source and Oligo-Miocene Kujung’s carbonate rock as key reservoir hydrocarbon explorations on all of East Java Basin.

Fine clastical rock from Ngimbang formation with interbedded claystone and sandstone with interclast coal is present in several sedimentation places with fluvial-deltaic depositional environment. Source rock potential on onshore and offshore East Java areas where mostly oil & gas exploration activities focus on Ngimbang formation was identified by good source rock, none the worse it need more evaluation further to know exploration continuity for further. And neither is carbonate rock dissemination in Oligo-Miocene, it’s need paleogeography identification with locally targets which match for reef built-up at that transgressive phase.

Rock characterization comprehension as basic on petroleum system was delivered this study to understand paleogeography as rock genetic come from. Recomendation this areas for explore are our research objective.

2. Method

By definition, paleogeography is visible image of geological condition in the past which focus on physical aspect and environment changing in the past (Lyell, 1919, J.Diana, 1860). This paleogeographic study was made based on several data integration, there are; structure (Tectonic), stratigraphy, lithology, and biostratigraphy. Derivative of biostratigraphy is bathimetry environment, rock sedimentation and fossils age.

Paleogeography also related to sea level change, either on local or global event at specific time. Those are reflected in lithologies which sedimented with fossil association, such as benthonic foraminifera or planktonic foraminifera which is abundant in specific environment and bathimetry.

3. Basic of Paleogeography Interpretation

In this study paleogeography built from several data such as focus on bathymetry index fossil and lithology. There many classification made to generate paleogeography. This study focus on bathymetry index fossils as primery data to define paleogeography conditions. This study also made some classification modification for making simple way classification Hedgpeth (1957), Berggren (1978), Ingle (1980), Tipsword et.al.b(1966), Brasier (1980), Bandy (1953), Schroder et al. (1988) research are adapted for this study (Figure 1).

4. Regional Geology

Mudjiono & Satyana (2005) mapped the paleogeography of East Java, in offshore area there are Muriah Trough – Bawean Arch – Tuban Trough – JS-1 Ridge – Central Deep – North Madura Platform and in onshore area there are terdapat West Cepu High – Kening Trough - East Cepu High – Ngimbang Basin – Madura Basin – BD Ridge – South Madura Graben – XX Ridge. The highs and lows are half graben system which fomed by Paleogene tectonic.

As the bigger picture, Java island is active margin Sundaland (West arm Australian microcontinent) Hall et. al. East Java formed by the subduction of Sundaland microcontinent and West arm Australian microcontinent, also affected by the Indian collision. It rotated the West arm and froming RMKS fault.

Rifting in East Java basin started in Paleogene as implication of eastern sundaland detached by Indo-australia and eurasia subduction. Ngimbang clastic dominated almost all the syn-rift depocenters, this formation is mainly recognized as source rock in this area.

After rifting, regional transgresive occured in East Java basin from Oligocene to Miocene. In high areas with shallow marine environment, corals started to grow which will be the source of Kujung formation. The coral clasts deposited in lower areas and become carbonate clastic. Kujung formation become the main reservoir rock in East Java basin.

At the end of transgresive phase, a tectonic event changed the paleogeography of East Java basin significantly. Rembang - Madura - Kangean - Sakala (RMKS) formed by west sulawesi microcontinent, bending of banda arc, australia - timor collision, and indo-australia and eurasia subduction (Figure 2b).
Generally, hydrocarbon generated in paleogene grabbing and migrated to higher areas. Hydrocarbon in offshore area is generated by Bawean Trough, central deep and South Madura. The source rock is rich organic shale from Ngimbang formation (Satyana, 2003)(Figure 2a). This formation mainly deposited in delta, lacustrine and shallow marine environment. Maturity started in middle miocene due to subsidence in low areas which causing enough temperature to generate hydrocarbon. Hydrocarbon migrated to reservoir (Kujung Formation) in high areas through carrier beds lateraly and faults vertically. The hydrocarbon exploration and exploitation are very intensive in high areas where the hydrocarbon accumulated.

5. Result and Discussion

5.1. Early Tertiary Paleogeografi (P6, 56-55 Ma)

Based on data and references extant now, Early Tertiary or around Paleosen (P6, 56-55 Ma) is great age to know basement configuration before whole East Java Basin riftting event (Figure 3a). Generally basement in this time was terrestrial environment. Mostly basement have terrestrial environment such as groundmass (paleosoil), breccia conglomerate, and palynomorps (Mayeripollis nayarkotensis). In this time transitional environment have indications such as interbedded carbonaceous shale, mangrove pollen fossils, coal, amber, and glouconite.

5.2. Middle Eocene Paleogeography (P14, 41 Ma)

Eocene time is petroleum system crucial age in East Java basin. At this age is sedimentation time of Ngimbang Clastic which is syn-rift phase. Base on analysis hydrocarbon there are mostly I & II kerogene type which is terrestrial – transitional depositional environment indication condition (Figure 3b). Fluvial – deltaic – intertidal environment have indications such as interbedded sandstone, carbonaceous shale, amber, coal, borrow palynomorf (Palmacollenites lutchensis), and fossils (Durio sp., Lanagiopolis microrugulatus, and Marginipolis concints). Inner – outer littoral environment have indications such as skeletal grains (shell & coral pieces), and larger foraminiferas. Inner – outer sublittoral environment have indications such as foraminifera fossils (Nummulites, Discocyclina, Pellatispira, Spiroclypeus, Operculina, Quinqueloculina, Heterolepa, Eponides, and Discorbis).

5.3. Late Oligocene Paleogeography (P22, 25.5 Ma)

Late Oligocene was the end of carbonate factory in this age. Late Oligocene base on tectonostratigraphy implied in post-rift phase which was Ngimbang Carbonate give-up. There was a base layer for Kujung formation build-up and sedimentation place (Figure 3c). Inner – outer littoral environment was dominantly as packstone, wackstone, grainstone, sandstone, and clystone. Inner – outer sublittoral environment have indications such as foraminifera fossils (Sphenolithus ciperoensis, Zygrhablithus bijugatus, H. recta, D. bisecta, Lepidocyclina (N) parva, Lepidocyclina isolepidinoides, Miogypsinooides praebaghsi, Heterostegina bornensis, Heterostegina bantamensis, Nummulites intermedius/fichteli., Globigerina angustiambilite (middle neritic), and Globigerina spp. (middle neritic, Fadel (2013)) Outer – upper bathyal environment have indications such as foraminifera fossils (Spiroclypeus, Eulepidina, Miogysina, Austrillina., Nummulites fichteli, Spiroclypeus spp., Lepidocyclina isolepidinoides, Miogypsinooides praebaghsi, Heterostegina praebaghsi, and H. bantamensis.), shale, and mudstone.

5.4. Early Miocene Paleogeography (N7, 16.5 Ma)

Early Miocene time. Early Miocene is important to understand Carbonate of Kujung formation. Sedimentation of Kujung formation is post-rift phase (Figure 3d). Intertidal environment was identity foraminifera fossils such as Haplophragmoides /Trochammina., Ammonia beccarii., and Textularia spp. Inner – outer littoral environment was foraminifera fossils dominantly such as Quinqueloculina., Eponides., Lenticulina., Haplophragmoides /Trochammina., Ammonia beccarii., Globigerinoides primolus., Rhodophytes., and Textularia spp. Inner – outer sublittoral environment have indications
foraminifera fossils such as Bolivina, Nodosaria, Operculina, Uvigerina aculeta, Lenticulina, Globorotalia acostaensis acostaensis, Globigerinoides ruber, Cibicidae, Bulimina spp., Gyroidina spp., Amphistegina, Lepidocyolina, and Ammonia. Outer – upper bathyal environment have indications foraminifera fossils such as Pyrgo spp., Globorotalia acostaensis acostaensis, and Globigerinoides ruber.

5.5. Middle Miocene Paleogeography (N9, 14.5 Ma)

RMKS fault influence appeared Middle Miocene time begun from onshore East Java in the northern part to offshore East Java. Bathimetry East Java offshore middle eocene time was shallow than southern part East Java onshore. Middle Miocene time was a maximum force sea level drop. There happened in the several East Java basin as dominantly fluvial deposite. This era was mostly Ngimbang formation sedimentation time (Figure 3e). Intertidal environment was indicated by foraminifera fossils such as Angulogerina., Aveolinella., and Haplophragmoides/Trochammina. Inner – outer littoral have indications such as foraminifera fossils (Lenticulina, Cibicidae, Sphenolithus heteromorphus, Angulogerina., and Ammonia indopacifica.), chalky limestone, reef banks, larger foraminferas, Mollusca debris and coral fragments (patch reefs possibly). Inner – outer sublittoral was indicated from foraminifera fossils as Bolivina., Uvigerina., Lenticulina., Globigerinoides sicamus., Gaudyrina spp., and larger foraminferas.

5.6. Pleistocene Paleogeography (NN19, 1.5 Ma)

Activation RMKS fault effect was clearly present in this era, specially there appeared on norther to east part East Java onshore and Pagerungan. Pleistocene time explained Paciran formation and those equivalents sedimentation as shallow marine environment condition. North - East West trend subduction compressional force in Southern Java made deformation and erosion predominantly (Figure 3f). Intertidal environment have indications such as foraminifera fossils (Ammonia beccarii, Quinqueloculina, A. trispinosa, Textularia spp., and Florilus.), coaly, claystone with limestone interclast, siltstone, and lignite. Inner – outer littoral environment have indications such as foraminifera fossils (Textularia spp., Elphidium spp., Lenticulina., Ammonia beccarii., and Quinqueloculina.), sandstone, interbedded carbonaceous shale, coal, chalky limestone, and corals. Inner – outer sublittoral environment was indicated by foraminifera fossils (Bolivina., Bulimina., Gyroidina., Lenticulina., Pullenia bulloides, Pulleniatina obiliquocolata, Uvigerina., and Elphidium spp.), sandstone, claystone, packstone, wackstone, and grainstone. Upper bathyal environment was indicated by foraminifera fossils (Globigerinoides quadrilobatus immaturus., Pyrgo spp., and Oridorsalis umbonatus.), plankton/bentos ration (50:50 – 70:30), mudstone, wackstone, sandstone, and shale.

Paleogeography and Source and Reservoir Rock Distribution.

Discussion about concept of paleogeography will not complete without the implementation/application in the field. In this study paleogeography will be related to petroleum system, specifically for source and reservoir rock elements. There are many references said that sediment clastics of Ngimbang formation is main source rock in East Java basin. The intercalation between shalestone with sandstone, sometimes with coal seam, makes this formation is rich with organic materials which later can form hydrocarbon such as oil and gas. Clastic rock of Ngimbang Fm. always be analogized as fluvio – deltaic environment or in tectonic setting always close with half-graben faults system. As we look in elevation there is a massive difference and sedimentation space between the highlands and lowlands until from wide to narrow sedimentation space.

One of the objectives from this study is trying to identify distribution of Clastic Rock of Ngimbang formation in East Java Basin. this study was conducted with same concepts of predecessor researchers, but only with larger research area, this study was supposed to give comprehensive understanding about clastic rock of Ngimbang Fm. regionally. Based on paleogeography map which is result of this study, probability of clastic rocks in Middle Eocene was quite widespread. Clastic rock of Ngimbang
good distribution from fluvio - deltaic environment, and shallow marine environment is illustrated in Figure 4. Some of interpolation method was conducted based on contour bathymetry which showed ‘valley’, for helping interpretation on western research area, because of short of data.

Beside of lateral distribution, this study also identifies, according to vertical position of locations where shale deposited, it has potential as source rock since the beginning of hydrocarbon formed (approx. 15 million y.a.) and has been in graben all this time. From some of references, it is known that “hydrocarbon window” in East Java Basin at elevation approx. 2500 m. From this data, the probability of discovering mature source rock is quite high in all graben.

In reservoir’s side, this study focussed at carbonate reservoir of Kujung formation. In Satyana, (2003), one of his publications explained quite detail about Oligo – Miocene’s Carbonate rock in Java Island. He classified two models of carbonate rocks forming, which are (1) Deposition on a Land-attached Platform and (2) Deposition on Offshore Isolated Platforms. In same publication, 5 facies was identified in this area, they are (1) Fringing Reef at Rim of Basement, (2) Basinal Mud Mound, (3) Patch Reef over Platform, (4) Shelf-Edge Barrier Reef, and (5) Pinnacle Reef over Offshore Isolated Platform. Meanwhile this study classify in simpler classification, they are (1) Patch Reef, (2) Berrier Reef, and (3) Pinnacle Reef Over Isolated Reef.

In reservoir’s terminology, porosity and permeability parameters also show good quality, for example in JS-1 Ridge area, from surviving well Camar-1, average porosity is 23% and permeability is 473.3 mD. While on North Madura Platform shows porosity 22% and permeability 253.3 mD. Similar with the Offshore area, on East Java’s Onshore area also shows good quality of reservoir with average porosity 16% and permeability 335.16mD. Different with three other areas that have been mentioned before, on Madura Strait area, reservoir rock data is limited. But based on geological and bathymetry models which is deepening on the East and limited local highground, then in that result in reservoir quality is less good than other areas.

6. Conclusion

There 6 (six) paleogeography maps have been made in this study comprise of : Early Tersier (P6 or 56 -55 mya), Middle Eocene (P14 or 41 mya), Late Oligocene (P22 or 25.5 mya), Early Miocene (N7 or 16.5 mya), Middle Miocene (N9 or 14.5 mya), and Plistocene (NN19 or 1.5 mya). All six paleogeography is considered showing evolution of East Java Basin paleogeography (Figure 3).

Paleogene is period that has become the key in East Java Basin, in this case become an initial point for basement setting which formed highland and lowland in halfgraben system like we see right now. Manifestation of halfgraben system has appeared since Middle Eocene’s paleogeography.

Clastic rock of Ngimbang formation, is dominated by lithology of shale-sand interbeded and some of coal seam, and believed as main source rock in East Java Basin. These rocks was deposited widespread and filled Paleogen’s grabens with sediment material source from vicinity highland. Laterally many places have probability for this roks deposited, because of on Middle Eocene there are some highlands which have Northeast – Southwest bearings, with probability of sediment paths on Western and Eastern of this highlands.

Kujung fm. in East Java Basin could be classifies by several reef types, thy are : Patch Reef, Berrier Reef, and Pinnacle Reef Over Isolated Reef (Figure 3d). This carbonate rocks of Kujung fm. was formed at Early Miocene and regional transgression phase where almost of East Java Basin area, was dominated by lithal – sublithal environment. Generally the quality of Kujung fm. carbonate rocks reservoirs shows Fair to Very Good quality.

7. Acknowledgement

This study was initiated by SKK Migas incorporated with University of Pembangunan Nasional ‘Veteran’ Yogyakarta and also several PSC (K3S) which operated in East Java Basin. This study has a purpose as motivation which is supposed to all stakeholders in oil and gas industry, from government, PSC, oil and gas contractors, consultant and forth, in facing recent impact of oil and gas price crisis. With this study we hope that all stakeholders remain active doing research and exploration as attempts
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8. References

[1] Boggs, Sam, J. R., 1987, Principles of Sedimentology and Stratigraphy University of Oregon, fourth edition.

[2] Cucci, M.A., 1995, Carbonate, System Tracts of an Assymetric Miocene Build Up Near Kangean Island, East Java Sea, Proceeding of International Symposium Stratigraphy in SE Asia.

[3] Hall, R., Clements, B., Smyth, H. R., Cottam, M. A., 2007, A New Interpretation of Java Structure (2007). Proceeding of IPA Convention and Exhibition.

[4] Hall, R., 2014, Indonesian Tectonics: Subduction, Extension, Provenance and More. Proceeding of IPA Convention and Exhibition.

[5] Johansen, K. B., 2003, Depositional Geometrics and Hydrocarbon Potential within Kujung Carbonates Along The North Madura Platform, As Revealed By 3D and 2D Seismic Data. Proceeding of IPA Convention and Exhibition.

[6] Prasetyadi, C., 2007, Evolusi Tektonik Paleogen Jawa Bagian Timur, Doctoral Thesis, Institute of Teknologi Bandung, Indonesia.

[7] M.K. Boundagher-Fadel., 2013, Biostratigraphic and Geological Significance of Planktonic Foraminifera, Second Edition, University College London, London.

[8] Mudjiono, R., Pireno, G. E., 2006, Exploration of the North Madura Platform, Offshore East Java, Indonesia. Proceeding of IPA Convention and Exhibition.

[9] Satyana, A. H., 2014, New Consideration on the Cretaceous Subduction Zone of Ciletuh – Luk Ulo – Bayat – Meratus: Implications for Southeast Sundaland Petroleum Geology (2014). Proceeding of IPA Convention and Exhibition.

[10] Widarmayana, I. W. A., Anggraini, N., Stephens, N., Musgrove, F., 2014. Banyu Urip and Other Cepu Block Fields Nucleation of Early Carbonate Buildups into Isolated Platforms. Proceeding of IPA Convention and Exhibition.
FIGURE 1. This study also made some classification modification for making simple way classification based on Hedgpeth (1957), Berggren (1978), Ingle (1980), Tipsword et al. (1966), Brasier (1980), Bandy (1953), and Schroder et al. (1988).

FIGURE 2. Regional stress in Neogene (Satyana, 2004), modified after Hall (2007) (a); Paleogene Paleogeography of East Java from Ngimbang formation (Satyana, 2005) (b).
FIGURE 3, Early Tertiary Time Paleogeography map (Economic basement) (a); Middle Eocene Time Paleogeography map (Ngimbang Clastics formation) (b); Late Oligocene Time Paleogeography map (Ngimbang Carbonate and initial of Kujung formation) (c); Early Miocene time paleogeography (Kujung Formation) (d); Middle Miocene paleogeography (Ngayong formation) (e); Pleistocene paleogeography (Paciran formation) (f).

FIGURE 4, Lower part of Ngimbang Formation paleogeography map (Satyana, 2009).