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UNRAVEL KENDENG PETROLEUM SYSTEM ENIGMA: RECENT UPDATE FROM TRANSECT SURFACE OBSERVATION OF KEDUNGJATI-DJUWANGI-NGAWI AREA, EAST JAVA

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ABSTRACT

Kendeng has been well-known as the main depocenter in East Java Basin with the complexity of hydrocarbon discoveries. This paper aims to evaluate petroleum elements in Kendeng onshore, integrating regional and surface transects in order to better understand how the system works and contribute towards future hydrocarbon exploration in this area.

Integrated study was conducted, including surface geological mapping, outcrop sampling, and laboratory analysis. Pelang Shale of the Djuwangi area shows poor to good organic richness. However, it is interpreted as being immature with low ability of generating hydrocarbon from mixed kerogen type II and III. Possible reservoir rock includes Miocene Kerek Sandstone with primary porosity ranging from 2-10% from maximum 6 m of thickness. Calcite cementation and longer period of burial has been interpreted to affect the quality of the sandstone. Oil seeps found in the Kedungjati, Djuwangi and Kedungwaru areas are indication of working petroleum system, related to trapping failure that cause the hydrocarbon migrated and charged the existing prolific fields in the Randublatung area.

Proven petroleum system in Kendeng has been well developed particularly in the Southern Madura Sub-Basin with marginal hydrocarbon reserves. Recommendation for future exploration in Kendeng will be towards the edge of Ngawi and South Madura Sub-Basin (Eastern Kendeng) with Kujung Reef and *globigerina* sand as the main reservoir target. Further study in the North of Bogomiring Field and West of Petiken-1 can help to identify hydrocarbon prospects especially when incorporate both surface and subsurface data.

Keywords: Kendeng, Petroleum System, Regional, Seepage.

INTRODUCTION

Kendeng has been attractive for many explorationist since 19th century. Regionally speaking, Kendeng is a basin with W-E depocenter and extended along the onshore part of East Java Basin to the Southern offshore of Madura. Exploration of this basin started in 1800's by Dutch when they studied numerous of hydrocarbon seepages as indication of working petroleum system in the area. In 1888, the first hydrocarbon discovery found in onshore of East Java Basin at the Kuti Field. However, history of East Java exploration reveals that hundreds of wells drilled in the area resulting only 25% of maximum success rate (IHS & Wood Mackenzie, 2012). Most of the drilled wells located in the North East Java offshore and Rembang. These indicate that : (1) East Java Basin is mature exploration area, (2) exploration activities in the basin were aggressive but small in discoveries, and (3) exploration prospects and maturity in Kendeng have not been proved compare to Rembang and North East Java offshore.

This paper focuses on petroleum system elements in Kendeng onshore area from East to Central Java. Based on regional study and constrained by surface transects, this paper attempts to address the following issues: (1) What is the possibility of Oligocene Pelang Shale as the oldest known beds exposed in Djuwangi area being potential source rock?, (2) How does the petroleum system work in the study area?, (3) Why did the majority of exploration wells in Kendeng area end-up with dry hole?, (4) What is suitable play concept and challenges towards future exploration in Kendeng area?

METHODS

Several methods were applied in order to better to achieve the objective of this study.

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a. Regional study :

   - Overlied surface geological map of Salatiga –Ngawi–Bojonegoro–Mojokerto-Surabaya quadrangles published by Geological Research and Development Centre (GRDC) with Digital Elevation Model (DEM)

   - Gravity anomaly map overlied with existing oil and gas fields

b. Integrated field mapping and geological observation, including structural and stratigraphic measurements in Kedungjati-Djuwangi-Ngawi areas

c. Laboratory analysis (geochemistry, biostratigraphy, and petrography)

d. Surface-subsurface correlation of Ngawi-1 well with surface section

SURFACE TRANSECT AND GEOLOGICAL OBSERVATION

Study areas are located within the onshore part of Kendeng. Field mapping and geological observation had been conducted for the past 3 years, located as the following Kedungjati, Djuwangi, and Ngawi areas (Figure 1.).

Kedungjati study area is located on theWestern part of Kendeng that exposes most of Miocene Kerek Formation. Biostratigraphic data reveals that oldest outcrop presence in this area is equivalent to the lower part of Kerek Formation (Middle Miocene, N13). Numerous measure sections suggest that this formation is composed of shale interbedded with limy sandstone (low sand/shale ratio) interpreted as being deposited as prograding deepwater fan with NW-SE paleocurrent trend (Cahyo et al., 2013). Structural pattern at Kedungjati tends to have NW-SE trend as fault propagation fold to the North, with some tear faults occur along the fold axis (Figure 1.a1.). Structural restoration was performed in order to measure deformation ratio, the result from cross sections showing average shortening 31.6 %, which leads towards high deformation processes. Oil seepage was found in Tuntang River, in the Southern part of study area, indicating the presence of trap mechanism.

Djuwangi study area is located approximately 10 km to the East of Kedungjati area. The area is well known for the oldest sediment in Kendeng being exposed to the surface. Pelang Formation is outcropped along the South of Djuwangi area, sitting unconformably with Kerek Formation at the South. Pelang Formation is consisted of pre-dominantly marls intercalated with thin beds of limestone, interpreted as being deposited in the deep marine environment (Outer Neritic - Lower Bathyal) during Late Oligocene - Early Miocene (N3-N4), constrained by the occurrence of small forams. This formation is interpreted to be equivalent to Kujung or Prupuh Formation, deve-loped in the Northern part of the area as carbonate reef complex. Representative samples were collected during the fieldwork for geochemical analysis. In terms of regional structure, Djuwangi area is slightly different compare to Kedungjati area, with relatively W–E structural developed as fault propagation fold (Figure 1.b1). Structural restoration was performed and suggesting a highly deformed area, with shortening of 53%. Additionally, oil seepage found at the Northern part of Djuwangi area.

Ngawi study area is located approximately 75 km Southeast of Djuwangi where Kerek and Kalibeng Formations are exposed. In this area, Kerek Formation is characterized by shale interbedded with pebbly sandstone, limy sandstone and volcanic tuff in the upper part. In addition, biostratigraphy analysis suggests older age of N16 or equal to Late Miocene. Kerek Formation is unconformably overlaid by Pliocene Kalibeng Formation composed of planktonic marl and reef limestone (well known as Klitik Member). Structurally, this area is still controlled by W-E fault propagation fold (Figure 1.c1), with structural restoration showing average shortening of 22 % suggesting slightly less deformed compare to Kedungjati and Djuwangi areas. In addition to above information, correlation was performed between surface section with Ngawi-1 well to improve understanding regarding the study area. This well was drilled by Coparex Blora and penetrated volcaniclastic, carbonates, and deep marine deposits (Lunt, 2013). Measured section from Ngawi area matches the successions observed in Ngawi-1 well, except the lower part of Kerek Formation, where oil trace occurs. However, there is no indication of oil seepage found in Ngawi surface area.

KENDENG PETROLEUM SYSTEM

a. Source Rocks

Pelang Formation is known the oldest exposed rock in Kendeng considered as potential source rock. Outcrop distribution is limited to approximately 1.8 km^2 wide (Lunt, 2013).None of the exploration wells

in Kendeng ever penetrated this interval, due to high operations risk. Geochemical analyses including Total Organic Carbon (TOC), Rock Eval Pyrolisis (REP) and Gas Chromatographs (GC) were performed based on outcrop samples collected nearby Pelang River, Jerukan and Kayen Villages to determine source rock quantity, quality and maturity.

Fine grained lithofacies of shale and marl from Pelang Formation yields 0.11 - 1.54 wt. % TOC, showing the quantity of organic richness ranging from poor to good. Potential yield (PY) calculation from REP indicates that whole samples have poor to fair (S1+S2 = 0.15 - 4.21 mgHC/gram rock) hydrocarbon source potential. Based on plot of HI against Tmax, it reveals that the source rock quality and maturity of Pelang Formation is dominantly consisted of mixed kerogen type II and III, categorized asimmature phase (Figure 2). Two samples indicate in mature phase (Tmax = 440 and 443ºC) and 1 sample show in postmature phase (Tmax = 546ºC).

Gas Chromatographic (GC) fingerprints of Pelang samples is characterized by decreasing concentration of higher molecular weight n-alkanes, Pr/Ph<3(low wax content), C31/C19<0.4 (low wax) on 30% of samples,50% of samples shows Pr/nC17 ratio <0.5 whereas 50% remaining has ratio greater than 1. Based on those results, it indicates the sediments were deposited under open-water condition/marine mixed with minor influence from inland/terrestrial (Figure 3.). Oil to source rock correlation did not possible to perform due to highly biodegradation of oil seep samples.

b. Kitchen

Kendeng depocenter formed before Sundaland and East Java Micro-Continent collision during Middle Eocene (after Prasetyadi, 2007). Moreover, based on regional gravity anomaly interpretation, W-E Kendeng depocenter can be divided into four sub-basins separated by intra basinal ridge. Those including Salatiga Basin (1929.6 km^2), Ngawi Basin (1414.12 km^2), Kediri Basin (1913.8 km^2) and Southern Madura Basin (10076.4 km^2) (Figure 4.). The first three basins are locatedonshore, while Southern Madura Basin is mostly located offshore.

c. Migration

Secondary migration of hydrocarbon may have taken place vertically along the faults after Pliocene uplifting to the North-, Northeast- and Northwest direction indicated by hydrocarbon manifestation on surface and existing proven oil and gas fields (Figure 4.). Several oil seeps found at Kerek, Kalibeng and Lidah Beds around Kedungjati and Jatikuwung-North of Djuwangi (Sukardi & Budhitrisna, 1992), and Kedungwaru (Supandjono et al., 1992).

d. Reservoir Rocks

Miocene Kerek sandstone is considered as possible reservoir rock in Kendeng stratigraphy. Generally, the sandstone is pre-dominantly composed of quartz and small foraminifera, with minor plagioclase, feldspar and lithic contents in calcareous cement. In terms of sandbody thickness and porosity, Kerek sandstone in Kedungjati has maximum 2 - 3 m of thickness with porosity ranging from 2 - 10% (Figure 5.). Djuwangi area has 3 - 6 m thick sandstone whereas Ngawi area has 1 - 2 m sand-stone beds with porosity ranging from 4 - 8%. Petrographic analyses reveal grain relationship of point-long and float contact, thus indicating that most of samples have been compacted possibly due to deep burial processes. Secondary porosity was observed in this formation, including moldic, vuggy and fractures.

e. Seal Rocks

Mio-Pliocene regional shales of Kalibeng Formation are interpreted to serve as seal rocks with good lateral distribution and thickness up to 700 m. In addition, Miocene shales of Kerek Formation possibly could be intra-formational seal.

f. Trap

Two trapping mechanisms are observed in Kendeng, structural and stratigraphic. Structural trap in this area has been proven and widely known as 3-way and 4-way dip closures that generated oil fields (i.e Lidah, and Kuti). Based on regional stratigraphic correlation of Kedungjati – Djuwangi - Ngawi measured sections to Ngawi-1 well, possible stratigraphic trap is levee channel complex below N14 marker (equivalent to Upper Miocene/Kerek Beds). However, this play is not proven yet considering the complexity of petroleum system in Kendeng area. Further investigation is needed in order to constrain existing interpretation.

DISCUSSION

Explorations in Kendeng area has been categorized as high-risk project, particularly when discussing oil source rock generation. Few exploration wells have drilled at the center of each sub-basin resulted in dry with minor oil and gas show indications (i.e. Ngawi-

1 and Toto-1 at Ngawi Basin, Jombang-1 at Kediri Basin, Pulungan-1, Banjar Panji-1 and Porong-1 at onshore of Southern Madura Basin).

Geochemistry analysis on Oligo-Miocene Pelang shale demonstrates low ability to produce hydrocarbon. The deepest well in Kendeng is Ngawi-1, drilled in 2002 with total depth (TD) of 8180 ft MD (Lunt, 2013). This well penetrated up to Miocene Kerek Beds then terminated due to overpressure issues. Despite lack of information in the Eocene interval, this strata is interpreted as the origin of hydrocarbon source surrounding Kendeng area.Satyana and Purwaningsih (2013) investigated biomarker characteristics of East Java oils on Metatu, Kawengan and Nglobo Fields. Their study indicates that the oil origin is possibly coming from fluvio-deltaic source facies from Eocene Ngimbang shales and coals. The authors are assuming that Kendeng has a separate sub-petroleum system that is not correlable with the Northern part. During syn-rift time on Mid-Late Eocene, the northern part was a terrestrial while Kendeng's paleogeography was at a deeper level of depocenter.

Proven petroleum system in Kendeng has been well developed in the Southern Madura Sub-Basin with marginal oil and gas reserves. Pleistocene four-way dip anticline closure and Late Miocene *globigerina* sand are the main structural and stratigraphic plays in this area. The sandstones are presence in Lidah Field located in the Northern edge of onshore South Madura Basin. However, stratigraphic correlation between surface section and Ngawi-1 well reveal low energy processes, indicating deep marine environment, and there is no similar sand found in Lidah Field (Figure 6.). During this time of deposition (N17-N18) the edge of Salatiga and Ngawi Basin was deeper than South Madura Basin. Moreover, unproven Middle Miocene Kerek stratigraphic plays are challenged by overpressure problem and tight reservoir issues. It seems that is misconception from previous researchers who attempted to correlate the sand with Lutut, Jaten and Ngrayong quartz rich sand.

Oil seeps found in Kedungjati, Djuwangi and Kedungwaru suggesting such leakage possibly due to trapping failure. Evidence of oil show from Ngawi-1 well can be correlated to structural cross-section of Ngawi outcrop (Figure 7.). In Kedungjati and Djuwangi areas, oil seepages located closed to the structural trend prove that hydrocarbon migrated to the North through faults and charge existing fields in Randublatung area (Figure 4.). Based on surface mapping, the leakage mechanism was potentially identified by area where seal rocks exposed (Kalibeng and Kerek Formation). Our data indicates that the biggest area exposure is in the western part (Kedungjati – Djuwangi - Sragen). Different level of deformation is observed between West and East Kendeng which is primary controlled by depth of detachment, angle, geometry and lithology.

Future exploration and step-out strategies in Kendeng would be focusing towards the edge of Ngawi and South Madura Sub-Basin (Eastern Kendeng). Potential Kujung Reef distributed along W-E edge of those sub-basins and located close to the Kedung Lusi, Randublatung, and Tiung Biru proven gas fields (Figure 4.). Prospect with low exploration risk is identified in the North of Bogomiring Field and West of Petiken-1 well. These prospects are targeting *globigerina* sand as the main reservoir objective (Figure 8.).

CONCLUSIONS

1. Kendeng is considered a complex area with slight number of hydrocarbon discoveries and numerous dry holes. It is classified as high risk exploration area.

2. Kendeng has a separate sub-petroleum system that can not be correlated to the mature and proven North East Java Basin.

3. Western Kendeng does not have a working petroleum system due to the following issues:

    - Hydrocarbon generation and charges. Pelang shales from Djuwangi area did not show sufficient evidence to prove ability generating hydrocarbon.

    - Low quality reservoir properties of Early-Middle Miocene Kerek Formation. The porosity ranging from 2 - 10% and different characteristic compare to Lutut, Jaten and Ngrayong quartz rich sandstone.

    - Trapping failure due to tectonic-related events (ie., uplifting and erosion).

    - Overpressure zone as being operational limitation to further prove stratigraphic play in deeper section.

4. Recommendation of future exploration would be towardsthe edge of Ngawi and South Madura Sub-Basin (Eastern Kendeng) for Kujung Reef stratigraphic interval as well as *globigerina* sand

prospects in the North of Bogomiring Field and West of Petiken-1 well.

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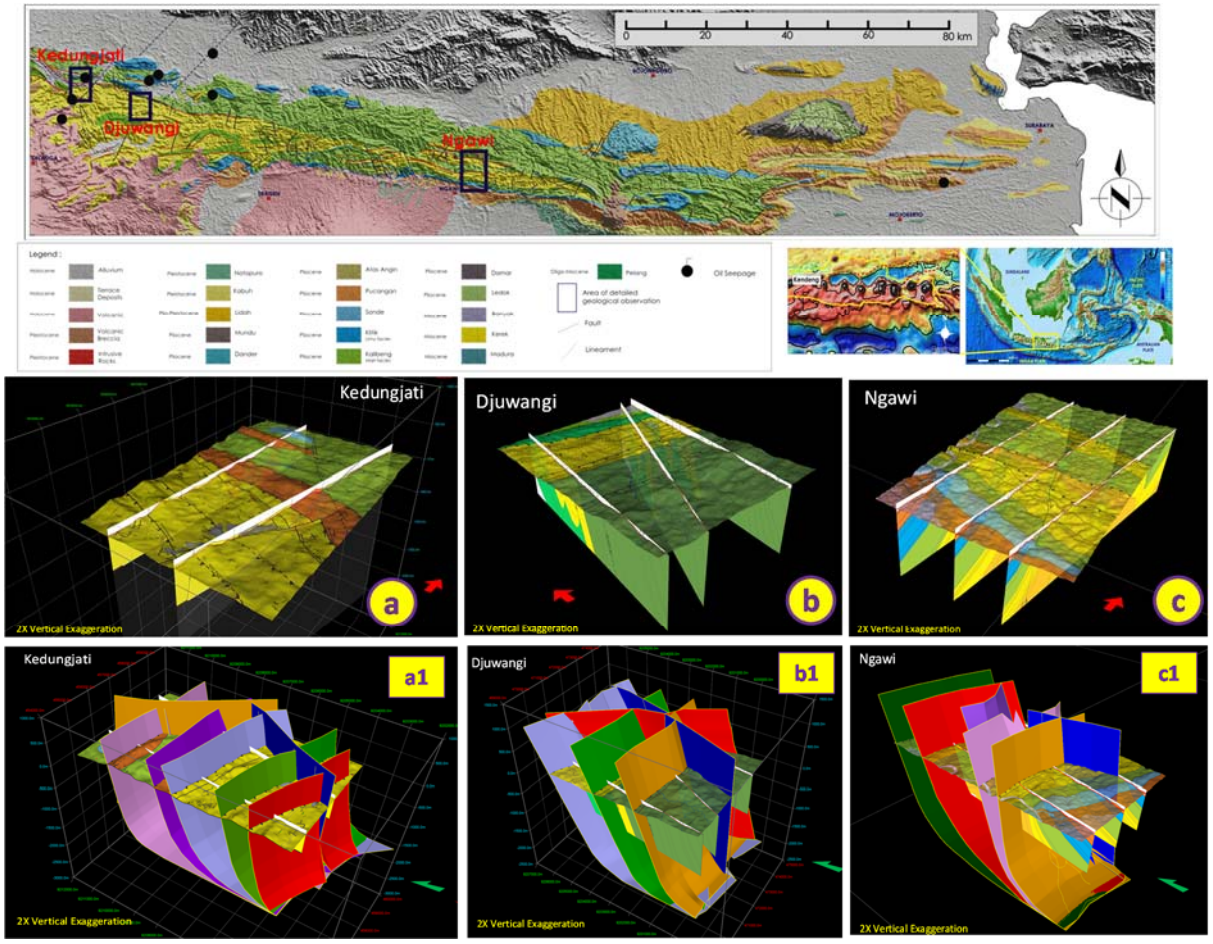

Figure 1 - Regional geological map of Kendeng and surrounding area (after Genevraye and Samuel, 1972; Noya et al., 1992; Datun et al., 1992; Pringgoprawiro & Sukido, 1992; Sukardi & Budhitrisna, 1992; Supandjono et al., 1992). Study area is in the blue boxes showing detail surface observation and each of structural models (a1, b1 and c1).

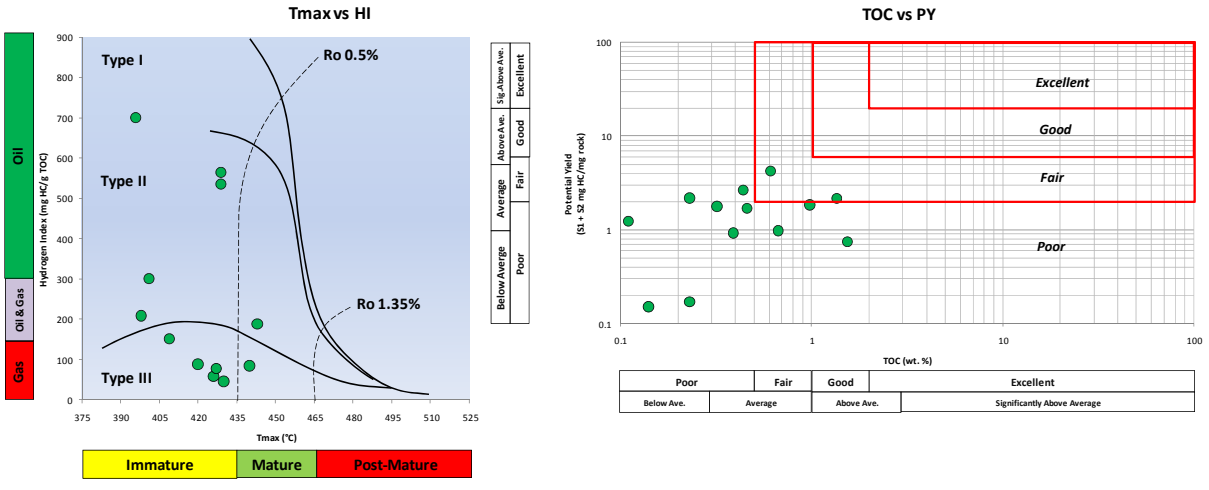

Figure 2 - Total Organic Carbon (TOC) and Rock Eval Pyrolisis (REP) of Pelang Shales. Crossplot Tmax vs HI (left) reveals that source rock quality and maturity of Pelang Formation dominated by mixed kerogen type II and III. Crossplot TOC against Potential Yield (right) indicates that quantity of organic richness ranging from poor to good with fair hydrocarbon source potential.

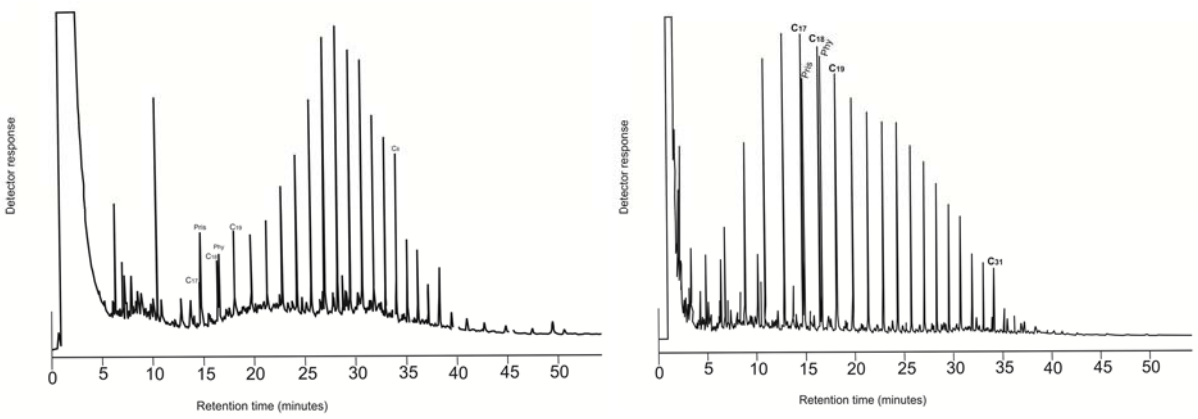

Figure 3 - Gas chromatograph fingerprints of Pelang shales suggesting marine environment (right) with minor influence from terrestrial (left) (Hartanto, 1992).

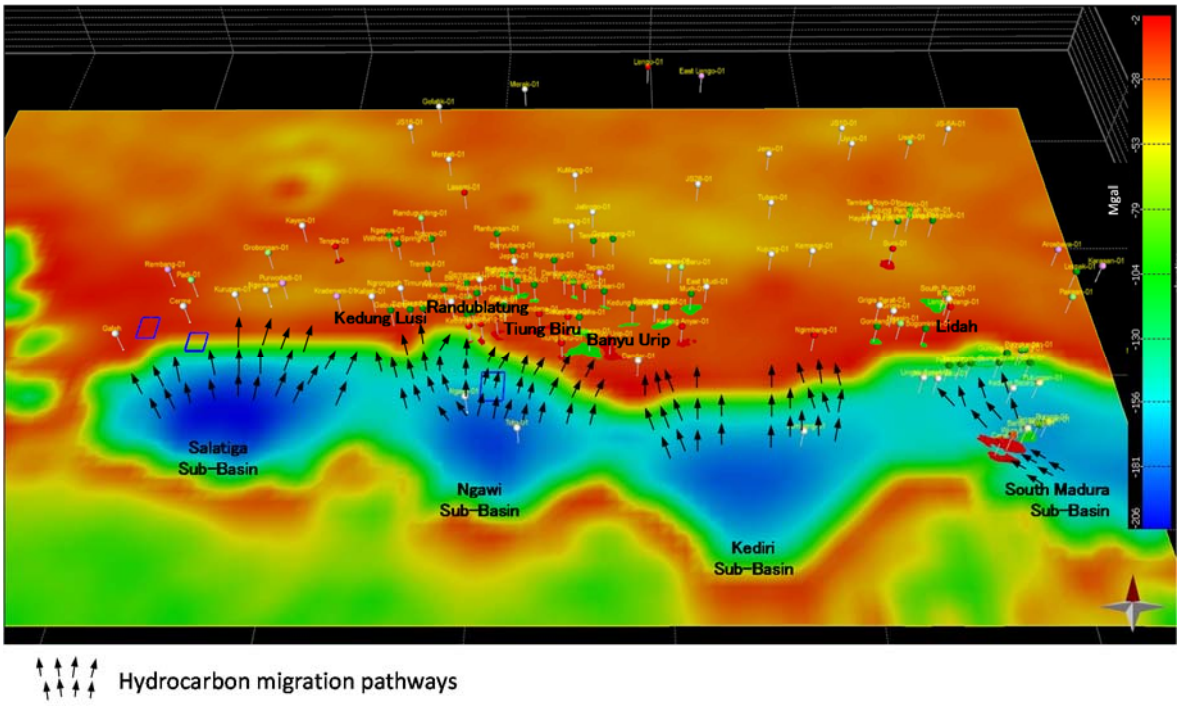

Figure 4 - Bouguer gravity anomaly of Kendeng area (source : International Gravimetric Bureau) overlied by existing oil and gas fields and the location of study area (blue boxes). It shows division of four sub-basins which is separated by intra basinal ridge. Hydrocarbon migration may have taken place vertically along the faults after Pliocene uplifting to the North-, Northeast- and Northwest direction indicated by hydrocarbon manifestation on surface and existing proven oil and gas fields

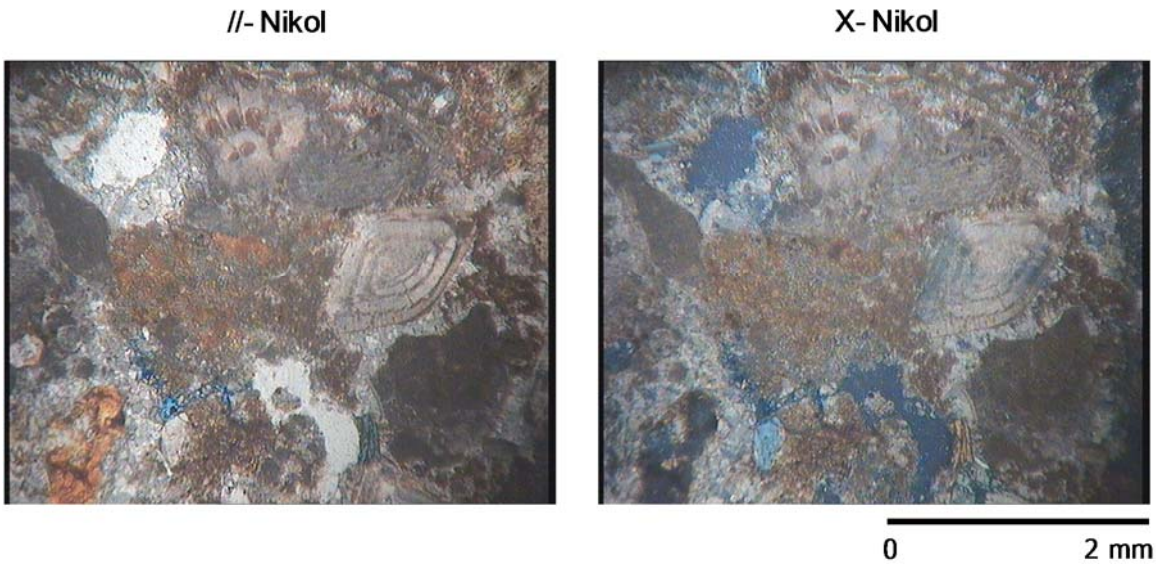

Figure 5 - Petrographic thin section of Kerek sandstone showing 10% porosity with fragments dominated by large foram and calcareous cement.

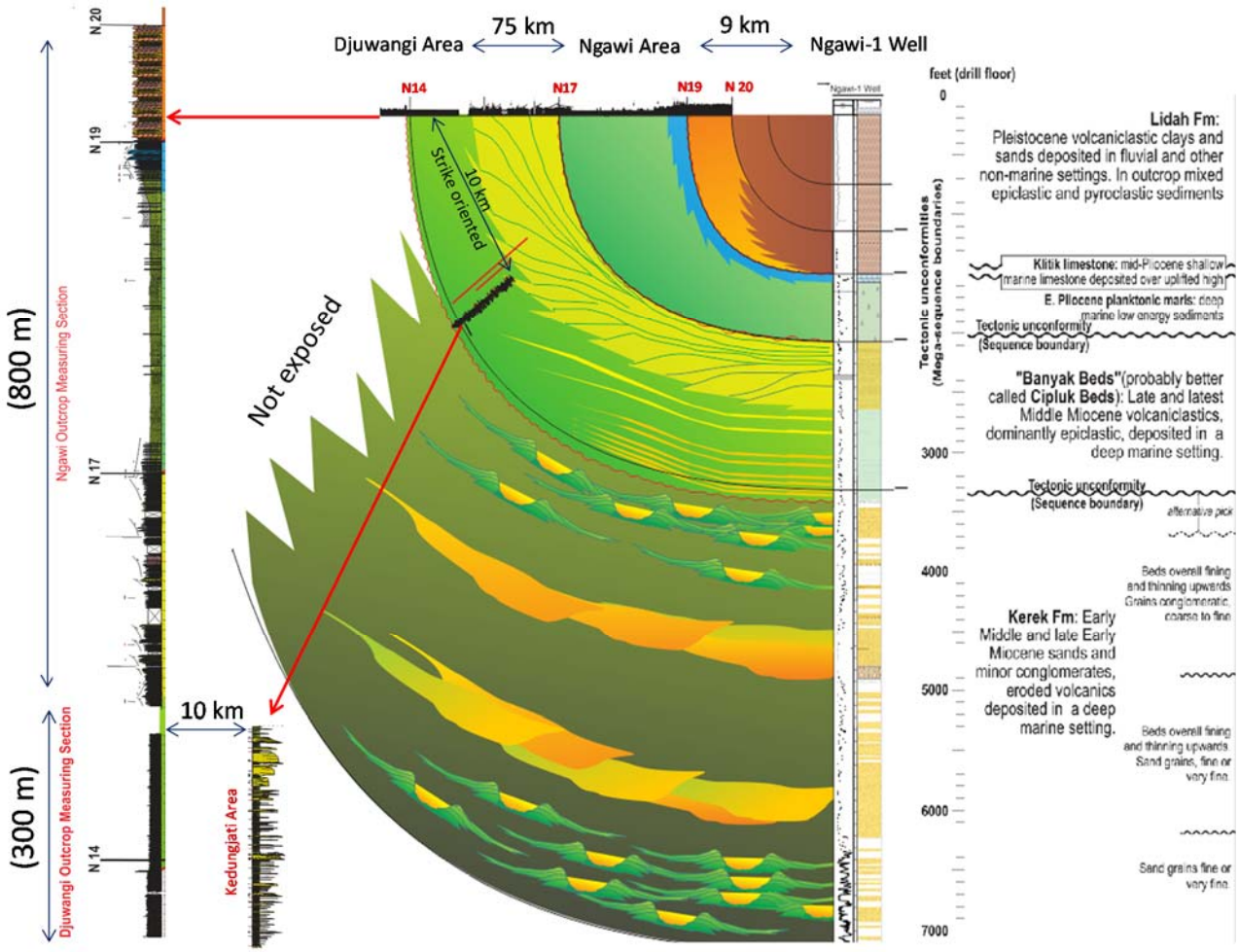

Figure 6 - Schematic facies and stratigraphic correlation between several surface measure section in Kedungjati, Djuwangi and Ngawi Area with Ngawi-1 well (Lunt, 2013). The correlation reveal deep marine environment in Salatiga Basin and Ngawi Basin,.During this time of deposition (N17-N18) the edge of Salatiga and Ngawi Basin was deeper than South Madura Basin where Lidah Field found

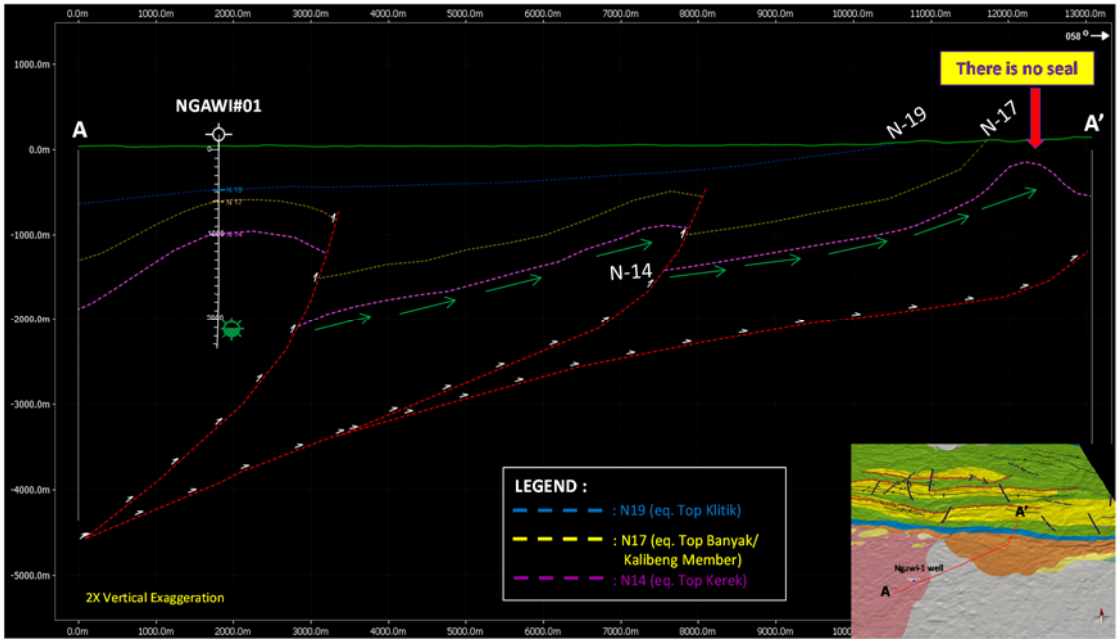

Figure 7 - Well to surface structural cross section in Ngawi area. This diagram explains the possibility of sealing failure causing the hydrocarbon migration towards the North through faults and charge existing fields in the Randublatung area.

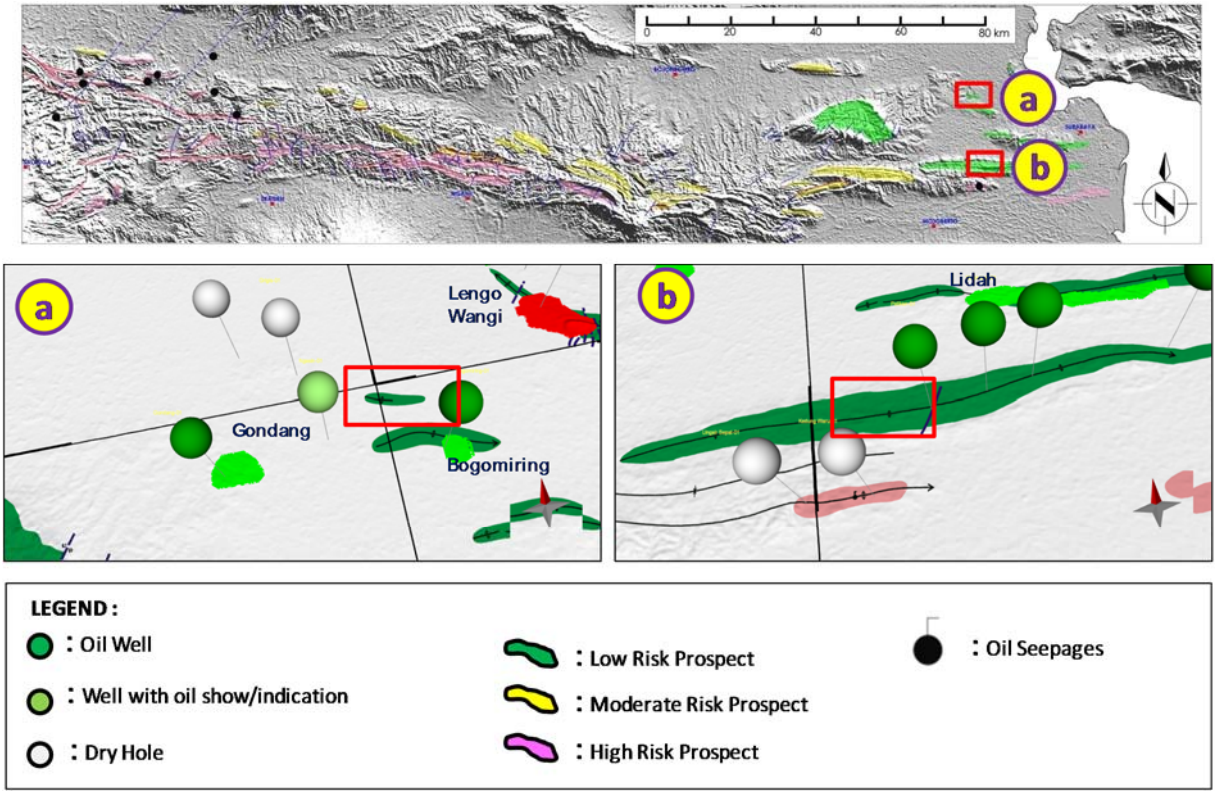

Figure 8 - Prospect map of Kendeng area. Potential structure identified in the Northof Bogomiring Field and West of Petiken-1 well (highlighted by red box) with *globigerina* sand as the main reservoir objective.