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STRUCTURAL REACTIVATION AND ITS IMPLICATION ON EXPLORATION PLAY: CASE STUDY OF JS-1 RIDGE

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ABSTRACT

Based on exploration discoveries evaluation and the density of wells–seismic trend, the Northeast Java Basin (NEJB) can be classified as a growing to mature area for hydrocarbon exploration. Furthermore, exploration hydrocarbon discoveries both in number and volume show a declining trend over the last 10 years. In order to increase the discoveries, an exploration strategy based on new concepts is required to develop ideas of unconventional exploration targets.

Most operators have banked their hydrocarbons from Kujung and Tuban Formations, well known and objectives in the NEJB. Kujung Formation has successfully treated many explorationists with horizons known as top class reservoirs. In the area of West Madura Offshore (WMO), Kujung Formation is divided into Kujung Unit I, Kujung Reef, Kujung Unit II and Unit III. This study explains paleotectonic evaluation of the WMO area, and suggests another potential play other than Kujung Formation. Seismic interpretation with some attributes and also ant-track method are applied to strengthen the exploration concept.

In the WMO area, the JS-1 Ridge is believed to have undergone at least three tectonic regimes: Paleogene tectonics (extensional-rift system), Neogene (wrenching) and Late Neogene (compresional: thrust-folding). This ridge is developed as one of several basement highs in the horst-graben system in the East Java Basin. JS-1 Ridge is well known as excellent target not only for reef deposits, but for the Development of syn-rift sequences in the Paleogene (pre-Kujung) and younger marine deposits (post Kujung). Another play that is quite interesting should be added to exploration in this area. Syn-rift play can be found in the western and eastern flank of JS-1 with Ngimbang Formation as the objective, whilst the post Kujung play can be emphasized on the flower structure pattern as an indication of wrench faulting. This wrench fault is responsible for tearing apart the Rancak and O.K. Formations during intra Miocene. In addition, the pattern of fractures in the basement is another interesting objective with opportunity for future exploration.

INTRODUCTION

The Northeast Java Basin (NEJB) extends from northern East Java to Madura Island and is a part of the Tertiary back arc basin system in East Java. This system is developed around the margins of Sundaland from North Sumatra to Central Sulawesi (Bransden and Matthews, 1992). The Sub-basin of East Java Sea is a part of an extensive and multi historical basin system that developed during Paleogene time.

West Madura Offshore Block is located relatively in the northern offshore area of Madura Island. There are four blocks owned by PHE WMO separated by relinquishment of EPSA contract. Two blocks are located in the northern area of Madura, one block is in the Madura strait and the other is located in eastern offshore area of East Java (near Pasuruan). PHE WMO's main block lies on one of horst feature known as JS-1 Ridge which is a basement high trending Northeast - Southwest and bounded by East Bawean trough on the West side and Central Depression on the east side (Figure 1).

METHODOLOGY

The understanding of tectonic evolution is fundamental in the preparation of this paper. East Java Basin had history cannot be separated from the tectonic history of Southeast Asia. However, tectonic approach of the JS-1 Ridge structural analysis is linked to plate origin, so some palinspatic analysis and paleo-Tectonic models of previous authors are necessary.

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Seismic data both 2D and 3D are used in this study, hence seismic attributes and other tools also were applied to analyze the structural reconstruction within JS-1 Ridge. Seismic attributes such as Acoustic Impedance and variance are needed to strengthen the analysis. Acoustic Impedance is needed to recognize tight and porous areas while the variance is needed to detect the non-continuity of seismic reflectors. Some horizons presumed to be metamorphosed due to overburden pressure can surely be recognized to have tight porosity. Applying Acoustic Impedance attributes to localize the area of porosity by fracturing, with low impedance value, and then carried to further analysis by Petrel's ant-track to determine the pattern of fractures after tearing by tectonic forces. The AI map was generated in the 50ms window to capture the possibility of fracture intensity in the basement level.

Structural evaluation in younger formations was carried out by applying seismic attributes. Several fault patterns are recognized both in section view and map view. Those patterns also are taken to the deeper analysis of tectonic regime and the presumption of structural re-activation within the area.

Regional Geology and Stratigraphy

The NEJB is dominated by several NE-trending basement highs and intervening half-grabens that formed during the Tertiary along the SE margin of the Sunda Plate (Manur and Barraclough, 1994 in Carter et al., 2005). The northern West Madura Offshore block is located close to the crest of one such basement high, known as the JS-1 Ridge.

The stratigraphy of this area is strongly affected by tectonic evolution during that time. Stratigraphy of the East Java Basin, especially for West Madura Offshore area is shown in Figure 2.

In the offshore northwest Madura, a Late Eocene-Early Oligocene clastic succession, known as the Ngimbang or "CD" Formation directly overlies a metamorphic and igneous pre-Tertiary basement (Mudjiono and Pireno, 2001).

In the Early to Middle Eocene, tensional stress regime triggered the Argoland terrane which docked to Greater Sundaland to be rifted and develop horst – graben configuration. This horst-graben system can be found along the northern part of present day East Java with West-East trend as Bawean arch, Tuban trough or Camar Deep, JS-1 Ridge and Central Deep. Active rifting in Eocene accompanied by basin sagging in Early Oligocene is assumed as the period of Ngimbang and pre-Ngimbang deposition. Phillips et al. (1991) divide the Middle Eocene Ngimbang Formation into three members: Ngimbang clastics, Ngimbang carbonates, and Ngimbang shale members. This formation was ended by intra-Oligocene unconformity that was overlain by Kujung carbonate.

The Kujung Formation is divided into three members - Kujung III, II, and I (from oldest to youngest). Kujung III is clastic-rich regressive sequence while Kujung II is transgressive sequence of shallow water carbonates and calcareous shales with localized carbonate build-ups over high topography. The Kujung I member is of Early Miocene age and typically consists of a series of carbonate buildups surrounded by mudstones and thin carbonates. The predominance of carbonates may indicate a decrease of clastic material input caused by either rising sealevel or the decrease of relief condition in the source area. (Satyana et. al).

During Middle Miocene, subsidence occurred almost over the whole area and drowned the carbonate platform. Massive progradation then occurred with open marine shale, silty limestone-sandstone stringers of 'OK' Formation. The 'OK' nomenclature refers to 'Orbitoid Kalc' whereas the lower part is known as Rancak unit of limestone and clastic (Ngrayong) unit while the upper part comprises limestone, reef and sandstone with claystone. This upper part of OK is assumed to be correlated with onshore Wonocolo Formation.

The Late Miocene to Pleistocene is the period of deposition of GL-MT Formation. The 'GL-MT' Formation can be subdivided into two members, from old to young, 'GL' Member and 'MT' Member. In the northern area of WMO contract area, GL comprises limestones, claystones, sandstones and siltstones whereas in the southern block is is dominantly claystone.

The MT Member is absent in the northern block although in southern block it can be found as predominantly claystone with minor sandstones. GL-MT is assumed unconformably underlain by the older Upper OK Member.

Tectonic Evolution Model

The breakup of Gondwanaland commenced about 160 Ma ago, with spread off the NW coast of Australia. Spreading between India and

Australia/Antarctica commenced about 128 Ma ago (Early Cretaceous) with the formation of new sea-floor along, and to the south of the present-day west coast of Australia (Veevers, 1984). The collision of small continental blocks rifted and separated progressively northwestwards from the NW Australian margin in the Late Jurassic−Early Cretaceous. These included the Argoland that drifted away from NW Australia during Late Jurassic. Argoland is now tentatively identified as the East Java, Bawean, Paternoster, Mangkalihat, and West Sulawesi blocks (Metcalfe, 2009).

Argoland drifted northwards during the Cretaceous and by Late Cretaceous times had accreted to SE Sundaland.

Paleo-Tectonic Model: Late Cretaceous

The hypothesis of Hamilton (1979) that the East Java Sea is underlain by a basement of quite different composition and origin to the Sunda Shield to the northwest. East Java, together with Bawean, Paternoster, West Sulawesi and Mangkalihat are suggested to be NW Australia Origin, called Argoland Terrane (Metcalfe, 2009). In the Late Cretaceous to early Paleogene, this Argoland docked to the SE Sundaland which is the southernmost part of Eurasian Plate. Argoland is assumed to be a small continent derived from the Exmouth Plateu of Western Australia which was accreted northwestward to tSundaland (Figure 3). The relative W-SW and NE-SW subduction of Australia Plate with Sundaland margin in Early Cretaceous met the Lupar subduction in the northern area. This tectonic configuration became more attractive when a continental fragment assumed as a part of The Big Australia drifted and approached that subduction complex. Right in the north of the subduction zone, the magmatic arc of Cretaceous outspreads with relatively similar trend to the previous Jurassic magmatic arc but shifted to the south. This Cretaceous tectonic configuration has been evaluated and reported by Sribudiyani et al. (2003) and other authors (e.g. Audley-Charles, et al., 1988; and Metcalfe, 1994)

Paleo-Tectonic Model: Paleocene – Eocene

During Early Paleocene, Argoland arrived and touched for the first time Sundaland (Figure 3). The presumption of the location is Lok Ulo, the assembly point. There is speculative suggestion based on litho-facies map of Central Java proposed by Bolliger and Ruiter, 1975 that mention during Early Miocene, Jokjakarta is located in a strait between West Progo Island (Nanggulan) and Jiwo Island (Bayat). Together with Bawean, those two islands are assumed as a part of western side of Argoland. The process became more terrific when the Argoland not only touched the southeastern part of Sundaland, but this micro-continent continued to collide with Sundaland. The collision of those micro-continents caused the magmatism to be halted. Furthermore, the subduction zone was uplifted by the impact of the movement, creating the Meratus Mountains in the eastern part and Lok Ulo Melange in the western part.

Oblique Subduction of Australian plate occurred as a relatively NE-SW regional system. This system brought the “un-original docked” Argoland to the condition of amalgamation and rotation in Paleocene – Eocene.

During this period, it is suggested that in the northern area of this amalgamated micro-continent there occurred two regional strike slip faults, Pamanukan-Cilacap Fault Zone (PCFZ) with its Sumatra trend and Adang-Lupar Fault in Borneo. The PCFZ has been interpreted to have translated the eastern extension of SW-NE pre-Tertiary subduction zone ±200 km to the southeast. The PCFZ also contributed to the change of NE-SW Pre-Tertiary subduction (Meratus trend) into relatively E-W java trend (Armandita et al., 2011). These tectonics models suggest that the prolific hydrocarbon zone was associated with Sundaland; or another speculative suggestion is derivation through the occurrence of Eocene sediments (pre-Ngimbang age) in the northern Platform of Kangean (Phillip et al., 1991). The Eocene sediments are assumed as pre-collision product carried when Argoland detached from Australia.

The back arc extension became more intensive in the Late Eocene resulting in the SE-NW trending configuration of horst-graben system accompanied by rift process in some locations of Paleogene East Java. The occurrence of PCFZ gave rise to further speculation that the Eocene extensional stress was accompanied by NW-SE push motion of the PCFZ. The SE area of Sundaland after Argoland docked is assumed as free area so the compression did not create such uplift or folding features.

Paleogene tectonic configuration can be described as segmented basement system of horst-graben style comprising (from west to east) Karimunjawa Arc, Muriah Trough, Bawean Arc, Bawean (Tuban) Trough/Camar Deep JS-1 Ridge, Central Deep, North Madura Platform, JS-5 Trough and Sibaru Platform (Figure 3).

Paleogene shelf edge is predicted along the northernmost limit of present day East Java with some embayments from the grabens. Some islands appeared as platform barriers, e.g. West Cepu High, East Cepu High and BD Ridge, right in the northern area of Paleogene volcanic arc. The volcanic belt sited in southern present day self of East Java and product is known as Old Andesite assumed equivalent with Jampang Fm in West Java .

The Js-1 Ridge as a part of segmented basement system is a horst bordered with Tuban trough and Camar Deep in the west and Central Deep in the east. This configuration was accompanied by rift system during Late Eocene to Early Oligocene and further marked as stratigraphic thickness contrast from hanging wall to footwall of Paleogene fault regime.

Paleo-Tectonic Model: Neogene

Collision of the Australian continent with northerly Eurassian Plate commenced in Early Miocene. The interaction of the northerly moving Australian continent and the westerly motion of Phillippine Sea Plate are believed causal to the called Neogene tectonic regime.

Other possible forces for Neogene fault movement reversal in the East Java Sea was compression resulting from blocking of the NW Borneo Trench in the late Early Miocene and the Sulawesi collisions. Furthermore, the Neogene Tectonic regime of East Java Sea is controlled by a regional wrench system called RMKS fault system. The drive mechanisms of RMKS are suggested by Satyana et al (2004) as multiple impact of:

- Westward stress driven by collision of some micro continent to the east of Sulawesi
- Westward stress due to the collision of Australia with Timor and anti-clockwise bending of the Banda arc
- Northward stress due to the subduction of the Indian oceanic crust beneath Java with northeasterly vector of plate movement.

A significant wrench zone, left-lateral slip in nature, strongly deformed a series of Late Oligocene to Pleistocene rocks in the northern coastal line of East Java and its eastern islands and offshore areas, including the JS-1 ridge.

Based on the regional setting of East and Southeast Sundaland, it is known that the RMKS Fault Zone occurred at the hinge belt or shelf edge to slope region of a geologic transition from the stable Eastern Sunda Shelf to the north (the Northern Platform) to the deep-water location to the south. Tectonically, the stable Eastern Sundaland is considered to overlie the expected micro-continent referred to as the Paternoster- Kangean or Argoland. Consequently, the RMKS Fault Zone is situated at the southern margin of the micro-continent (Satyana et al., 2004)

Along the RMKS Fault Zone, flower structures are identified on seismic sections, showing basement-involved, deeply-rooted vertical major faults with upward diverging splays that have mostly reverse separations. In map view, these splays are mapped as fold and fault belts trending west-east and west northwest-east southeast. Extensional component of the wrench zone subsided the Paleogene rifted blocks such as the Central Deep and formed a number of normal faults. Tectonic inversion related with both pure and straightforward shear deformation is observed along the fault zone. Shale diapirism commonly occurs to the south of the fault zone and its occurrence is related to wrench tectonism in thick shale sequences deposited rapidly to the south of the RMKS Fault Zone (Satyana et Al, 2004).

Shale diapirs cannot be found in the northern part of this fault system, especially in JS-1 ridge area but some flower structures appear in both flanks of JS-1 ridge. SW-NW Horst-Graben system of Paleogene in the East Java setting such as Cental Deep, East Bawean, JS-1 Ridge or East Cepu High relatively in stagnant phase of structural style during Tertiary. Younger deformation of intra Miocene (RMKS) triggered those grabens to be drowned as the impact of tensional component of sinistral (left) movement (RMKS).

The influence of the RMKS system is also appears in JS-1 Ridge area. Some flower structures can be identified on seismic lines en echelon pattern in map view (seismic slice). For structural analysis, it is suggested that simple shear system can be applied on JS-1 Ridge area whereas the old configuration of horst (basement high) was strongly affected by strike slip system (Figure 4).

Paleo-Tectonic Model: Late Neogene (Quaternary)

The East Java Sea Basin was formed during the Tertiary along the southern margin of continental Sundaland. Fundamental structures within the basin have been controlled by interaction between the

Indo-Australian Plate and Sundaland. The predominant NE-SW structural trend in the northern part of the basin resulted from accretion along the southern margin of Sundaland in the Cretaceous and Early Tertiary. Volcanism in the Miocene resulted in the emplacement of the Java Geanticline along the present-day southern margin of the East Java Sea Basin. In the Plio-Pleistocene, collision between Sundaland and Indo-Australian Plates resulted in left lateral shear in major E-W zones and produced the predominantly E-W structural trend in the southern (onshore) part of the basin.

Middle to Late Miocene uplift occurred in the eastern part of the basin, which was associated with a series of E-W trending, down-to-the-south normal faults. There was further uplift in the Late Miocene to Early Pliocene. The most intense period of deformation began in the Late Pliocene and continued through to the Early Pleistocene. Folding, with associated thrust faulting, was particularly intense in the west. There was lateral movement along the Madura Hinge during the wrench faulting.

Intense shale diapirism was associated with this Late Pliocene to Pleistocene tectonism, with some folds being breached at the surface. The Sundaland area was also tectonically active during the Late Pliocene to Pleistocene. Wrenching may also have occurred along at least some pre-existing faults.

The Late Neogene tectonic is assumed as compressional regime accompanied by structural re-activation of old systems. The possible geologic configuration caused by this Late Neogene Regime can be recognized from south to north as ge-anticlines and associated shale diapirs, flower structures (wrench faults), and reversal faults of old structures (Figure 5).

The JS-1 ridge as a part of a horst-graben system was also affected by late Neogene compression. Some reversae faults and structural rejuvenation seems to occur along the horst although shale diapirs cannot be found. There is a speculative suggestion in normal faults being rejuvenated after dragging by RMKS system. The possible configuration following effects of at least three tectonic regimes present the chance of hydrocarbon accumulation in shallow targets.

Geology Structural Analysis

The aim of this study is to determine hydrocarbon potential in JS-1 Ridge other than Kujung formation with consideration for structural re-activation as direct impact of tectonic evolution. The JS-1 ridge as a part of segmented basement set of North East Java is assumed to have endured at least three tectonic regimes from Paleogene time, and Neogen to Late Neogene. The structure analysis in this paper will be discussed for each tectonic regime.

Paleogene Structures

Regional tectonics during this time were driven dominantly by northeastward movement of the Australian Plate to Sundaland. The result of this interaction was subduction along Java-Meratus (Meratus trend) in Late Cretaceous. In the Paleocene, the Argo micro-continent is assumed to impact the southeasternmost part of Sundaland. North-south regional compression came from convergent movement of those plates, accompanied by compression element of PCFZ during Eocene. As counterweight, west-east tension occurred in some areas including the northern part of Argoland. The Paleocene-Eocene back arc extension is considered as the impact of the horst-graben set found in Northeast Java Basin. These configurations of segmented basement bring speculation to the occurrence of rifting in the area.

JS-1 ridge is one of horst body in the segmented basement system in East Java. Regional fault pattern caused by Paleogene tectonic regime is a set of major normal faults trending relatively northwest-southeast. This trend is quite different with prior trends of north-south driven by W-E tensional stress and probably due to the anti-clockwise rotation during Paleocene to Eocene. The old N-S fault pattern still can be recognized in the southern area of JS-1 ridge.

Neogene and Late Neogene Structures

During this period, JS-1 ridge was influenced by regional strike slip fault known as RMKS fault. This fault is well explained by Satyana et al., 2004. JS-1 Ridge as a horst body in segmented basement system in the north area of RMKS fault received dragging motion of the RMKS system. Some flower structures appear in the northern and southern flank of JS-1. En echelon pattern also can be recognized in the map view. Fault pattern during this period seems only a shift from the old pattern as the impact of W-E sinistral movement of RMKS. The negative flower structures appear to tear Kujung formation and other Miocene formations. This structural re-activation can be observed in the seismic lines. A plain structure analysis using simple shear model can be applied here and the result seems to match.

En echelon faults trending relatively N-S occur in the western part of the north and eastern part of the south flank of JS-1 ridge. The major fault is NE-SW normal fault believed as an old pattern of Paleogene horst-graben system.

During the Late Miocene to Pliocene, compression tectonic regime prevails in the region. JS-1 ridge faults were reactivated by NS compressional stress. Some inverted structures can be found along the horst body of JS-1 ridge, tear the sediments up to Late Miocene OK formation. Several normal faults were reactivated as the horst block uplifted. Structural reactivation during this period saw motion along existing planes without making new patterns or direction.

Implication on Exploration Targets

The major exploration target in West Madura Offshore concession is Early Miocene Kujung reef build-ups. This formation is very good target present over most of the whole area of JS-1 ridge. The JS-1 is recognized not only for the reef deposits, but also for the development of syn-rift sequences in Eocene (pre-Kujung) and younger marine deposits (post Kujung) (Figure 6). Pre-Kujung targets refer to Early Oligocene Ngimbang Fm and older formations if present. The occurrence of pre-Ngimbang sediments in Kangean area raises speculation for targets older than Ngimbang Fm. At basement level, seismic interpretation of variance attributes in the southern area found two interesting patterns of relatively N-S and NW-SE are identified across the JS-1 ridge (Figure 7). These patterns are assumed as paleo-channel and possibly are the product of Paleogene tectonics. This channel model seems to be potential debris sediments analogous to Berai carbonate debris of Paternoster (Pireno, et al, 2009). Another interesting finding is the possibility of a metamorphic layer below the Ngimbang Fm. Some Wells penetrated to so called economic basement have been recorded in West Madura Offshore area and indicate the presence of meta-sediments of volcanic origin at more than 8300 feet depth. Structural analysis using ant-track method points out the possibility of fractures in this layer (Figure 8). Fractures can be recognized in whole area of JS-1 ridge and the intensity should be addressed to the tectonic regimes. Each tectonic activation results in sets of fracture patterns. The major pattern of the fractures is NE-SW and the perpendicular minor pattern rips along the area. The fracture intensity is checked by applying Acoustic Impedance attributes and the result shows a match between fracture pattern (ant-track) and the AI map. In the AI map, low impedance is indicated by the distribution of red area. The red area indicates a velocity through a relatively lower density media than the surrounding area. These low density values are considered caused by the presence of lithology variations or ripped by fracturing. The northern area of JS-1 has very steep flank while the southern is more slope. Considering hydrocarbon migration, the ramp has more chance to be filled then the steep flank. We suggest the southeast of JS-1 ridge as the prime area for fractured basement play.

Structural re-activation during Neogene time brings another opportunity for hydrocarbons in the post Kujung section. From earliest days, operators have only found gas shows in Rancak and OK Formations. This information confirms the petroleum system, especially the migration process. The en echelon pattern can be clearly recognized in the northwest and the southeast area and are considered to be the impact of RMKS fault. The re-activation of older faults by new tectonics regime brings potential to Post Kujung formations. The presumption of fault inversion comes from southern area of JS-1 ridge where younger layers pinch out to older layers toren by flower structure. Structural inversion is usually caused by direct re-activation of pre existing normal faults. In this case, local inversion is supposed to be the consequence of alternating phases of transtension with negative flower structure and transpression with positive flower structure.

Finally, the Rancak and OK Formations have potential to be filled by hydrocarbons through structural mechanism. Normal faulting can be the way to bring the Post Kujung layers down and entering a range of migration (Figure 9). Flower structure is a perfect style for this hypothesis solving negative aspects of hydrocarbon charge/migration.

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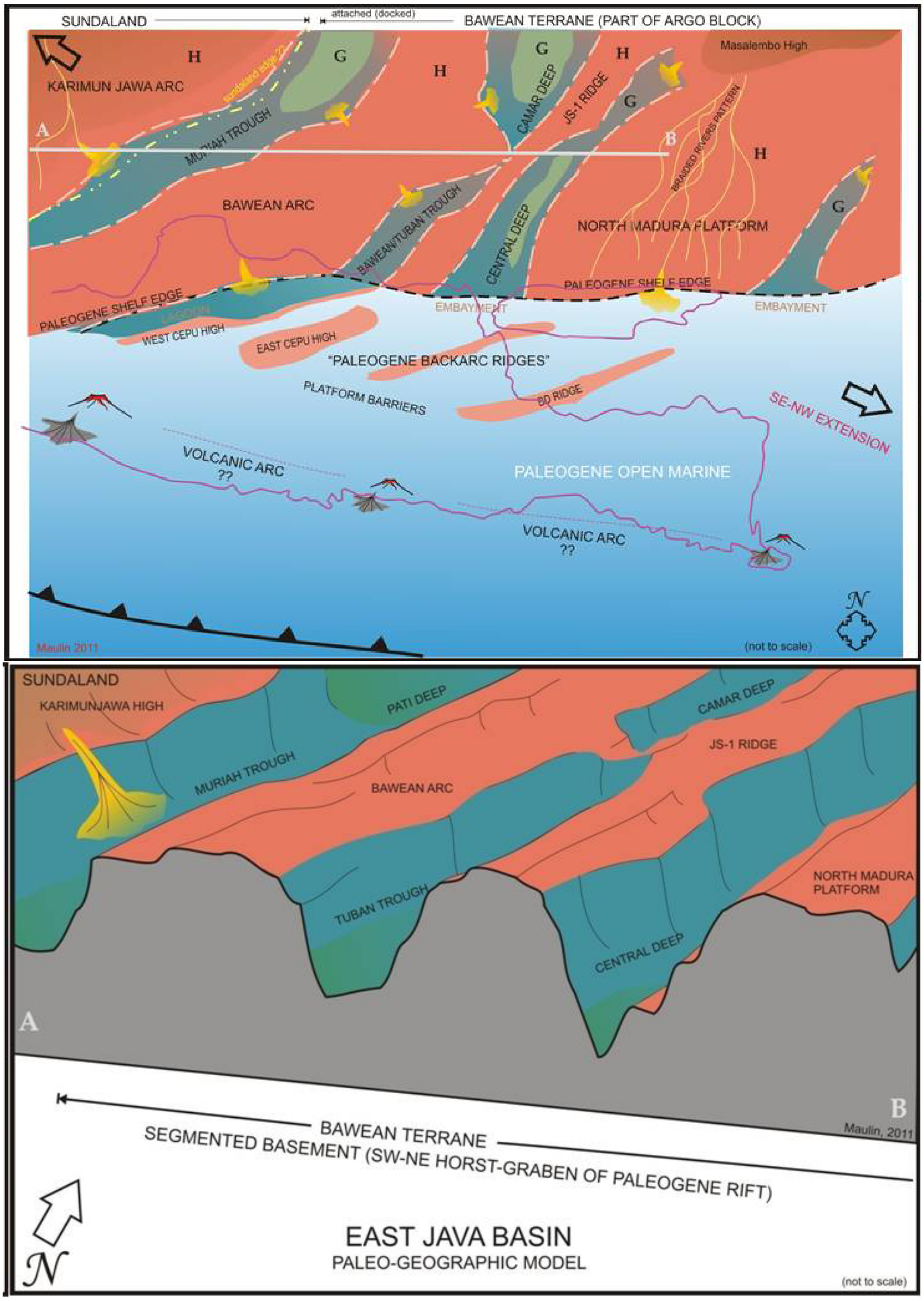
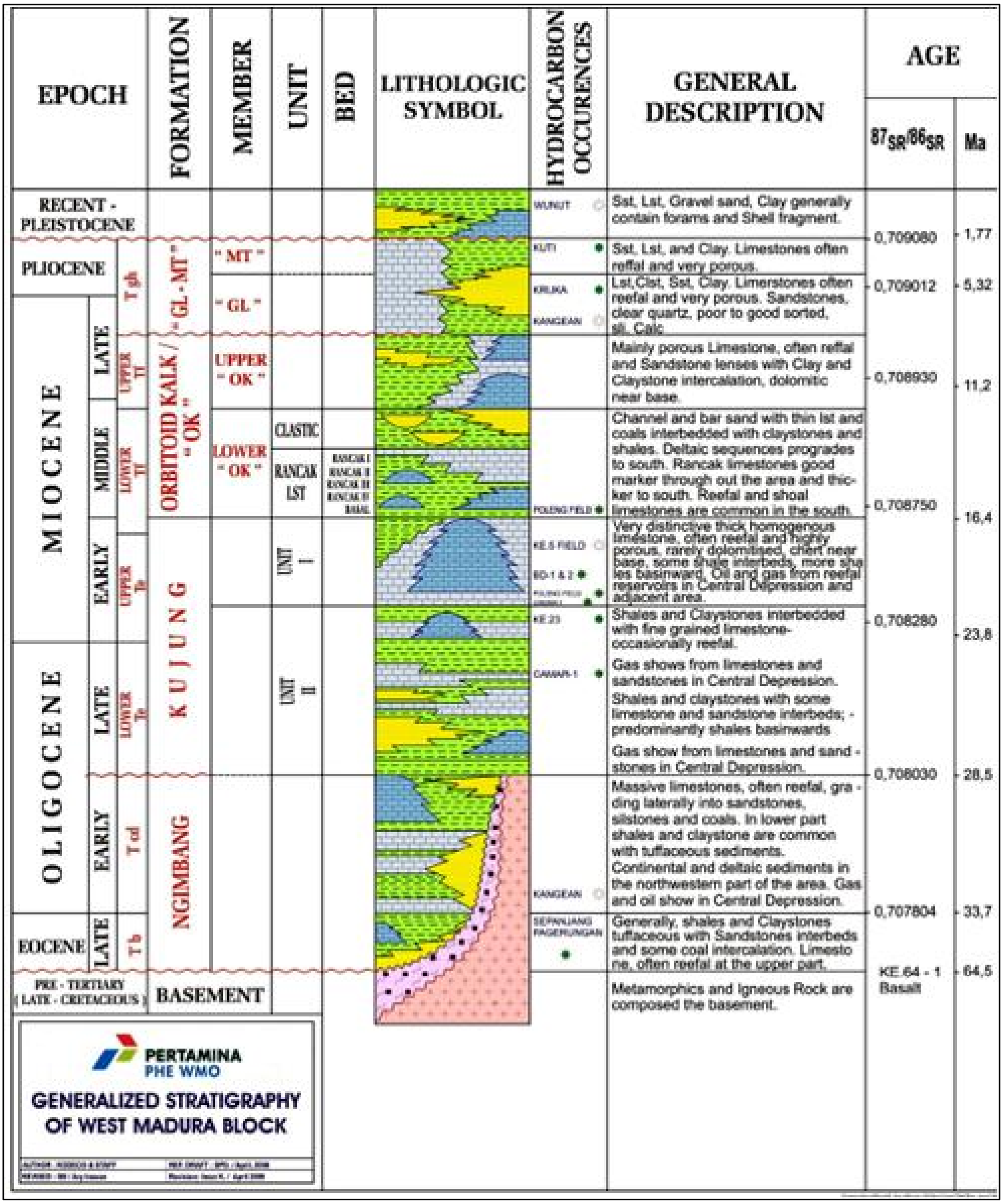


Figure 1 - Paleo-geography map of East Java Basin and its regional section



Sst, Lst, Gravel sand, Clay generally contain forams and Shell fragment.

Sst, Lst, and Clay. Limestones often reffal and very porous.

Lst,Clst, Sst, Clay. Limerstones often reefal and very porous. Sandstones, clear quartz, poor to good sorted, sli. Calc

Mainly porous Limestone, often reffal and Sandstone lenses with Clay and Claystone intercalation, dolomitic near base.

Channel and bar sand with thin lst and coals interbedded with claystones and shales. Deltaic sequences progrades to south. Rancak limestones good marker through out the area and thicker to south. Reefal and shoal limestones are common in the south.

Very distinctive thick homogenous limestone, often reefal and highly porous, rarely dolomitised, chert near base, some shale interbeds, more shales basinward. Oil and gas from reefal reservoirs in Central Depression and adjacent area.

Shales and Claystones interbedded with fine grained limestone-occasionally reefal.

Gas shows from limestones and sandstones in Central Depression.

Shales and claystones with some limestone and sandstone interbeds; - predominantly shales basinwards

Gas show from limestones and sandstones in Central Depression.

Massive limestones, often reefal, grading laterally into sandstones, silstones and coals. In lower part shales and claystone are common with tuffaceous sediments. Continental and deltaic sediments in the northwestern part of the area. Gas and oil show in Central Depression.

Generally, shales and Claystones tuffaceous with Sandstones interbeds and some coal intercalation. Limestone, often reefal at the upper part.

Metamorphics and Igneous Rock are composed the basement.

Figure 2 - Generalized stratigraphic column of West Madura Offshore

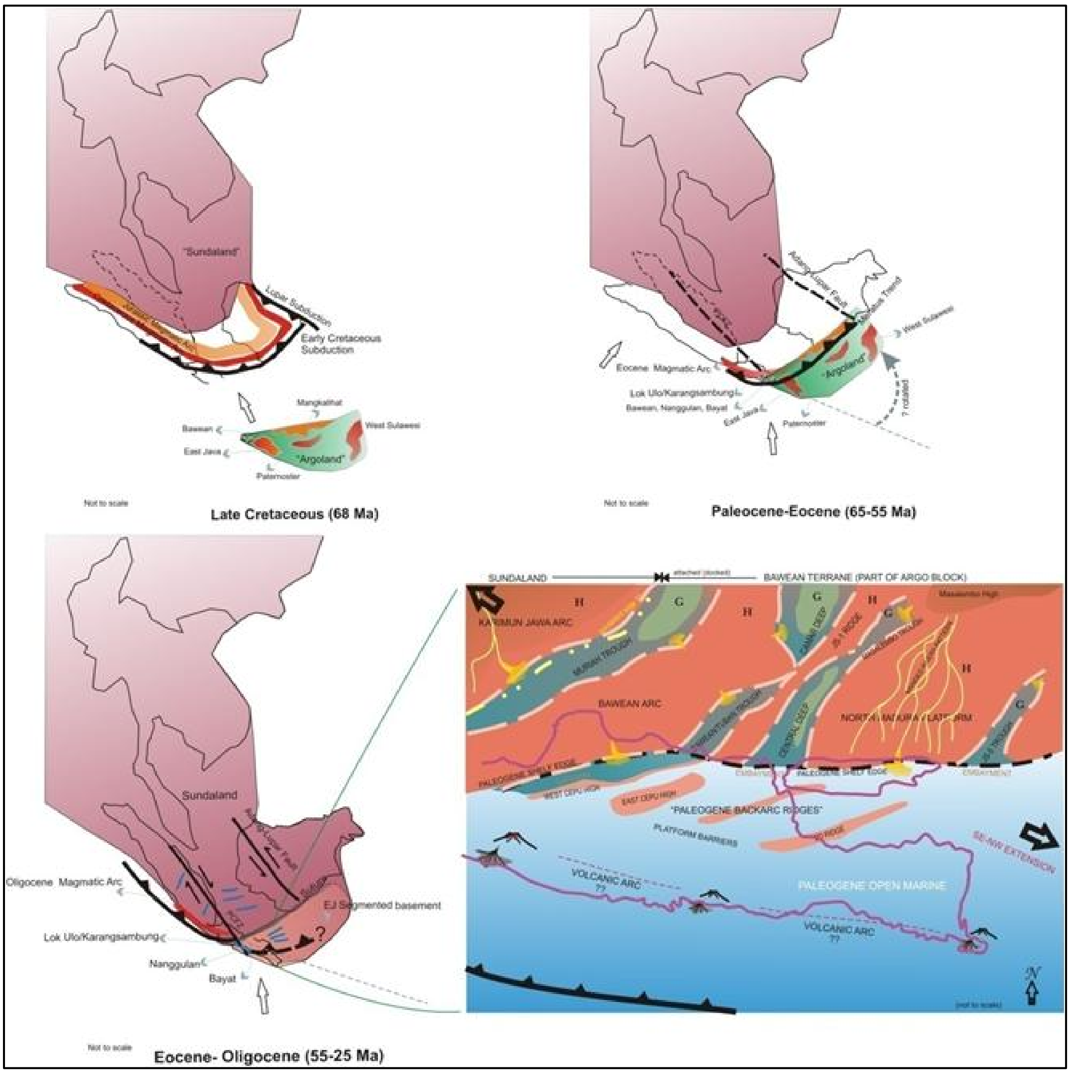


Figure 3 - Paleo-tectonic model of East Java Basin (modified after Sribudiyani, 2003)

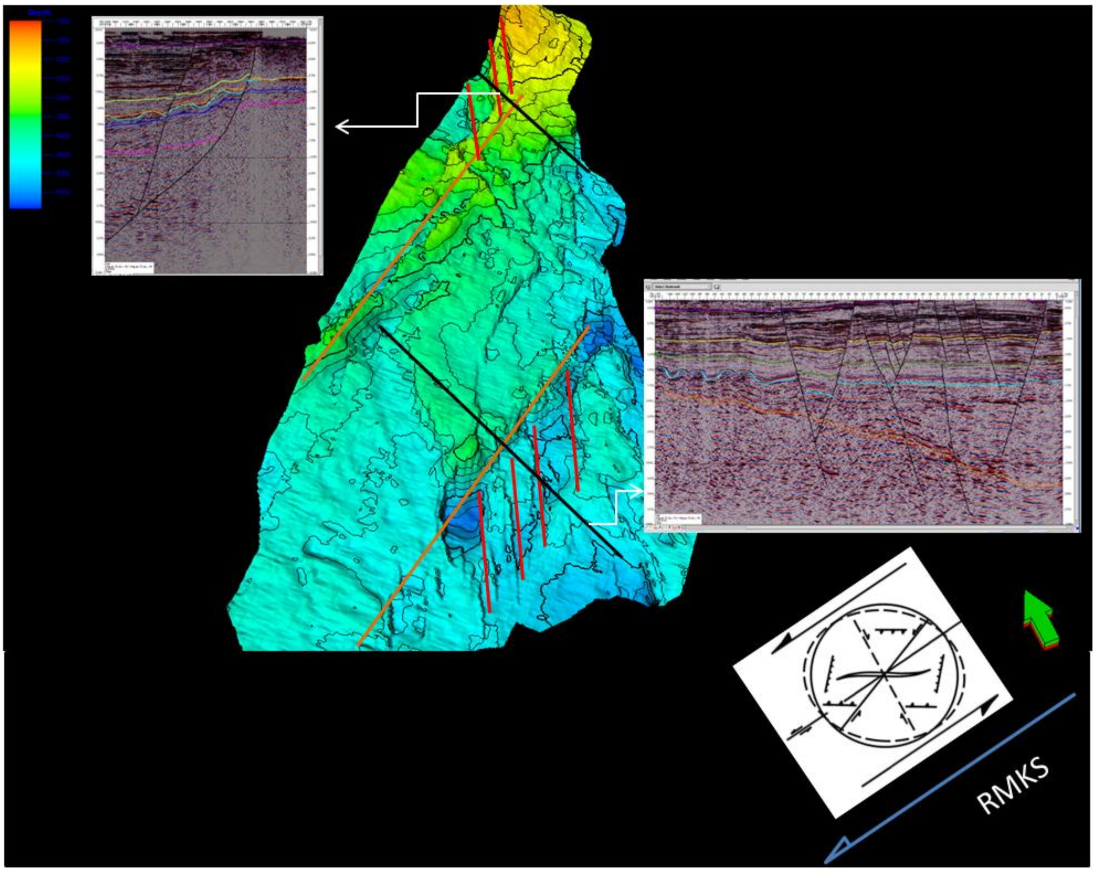


Figure 4 - The influence of RMKS in the JS-1 ridge (Neogene tectonic regime)

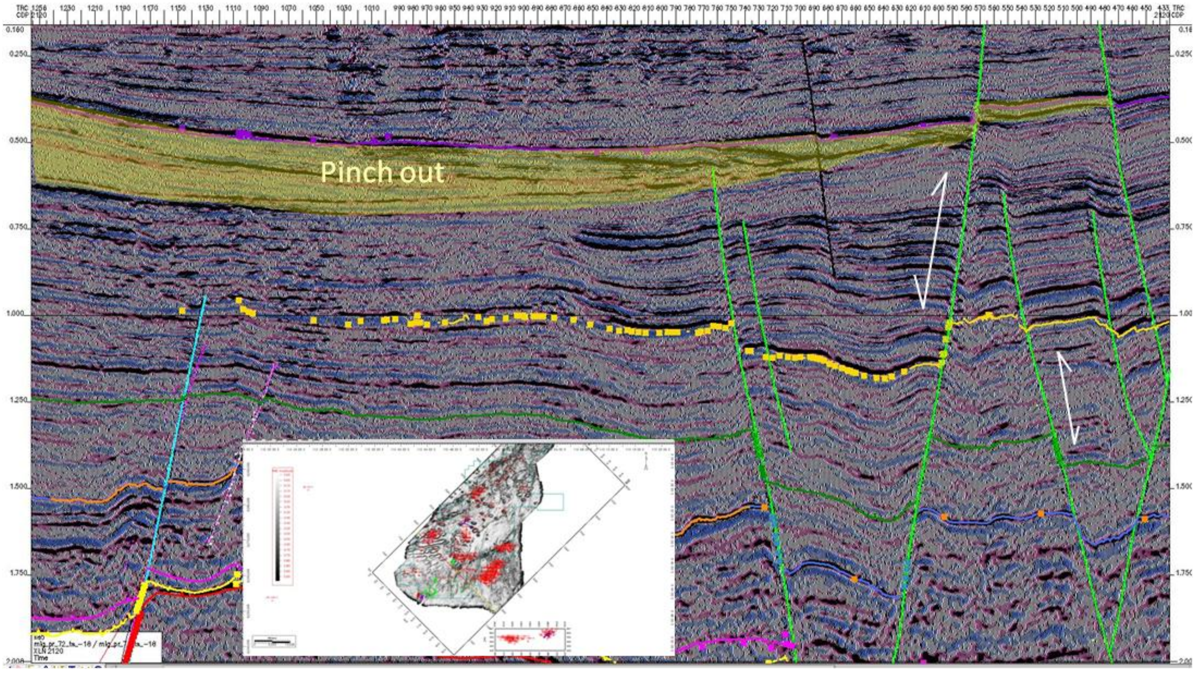


Figure 5 - Inversion fault as impetus of structural reactivation in the southern area of JS-1 ridge

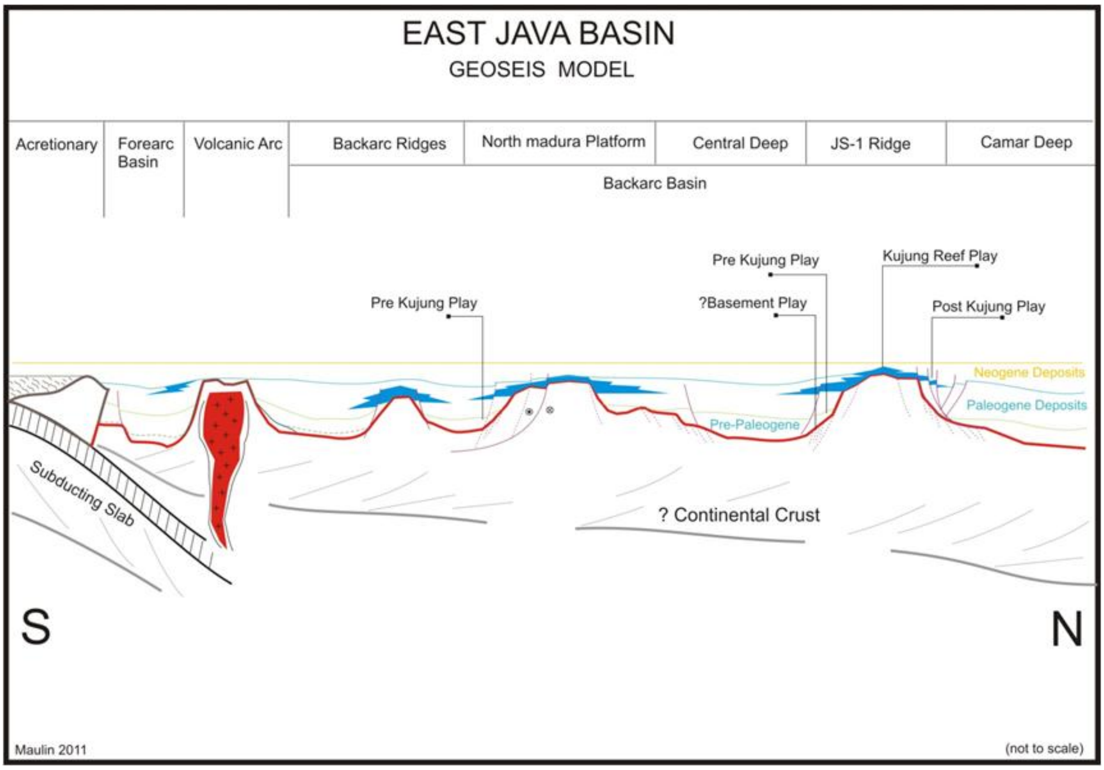


Figure 6 - Geoseis model of exploration play concept in Northeast Java Basin

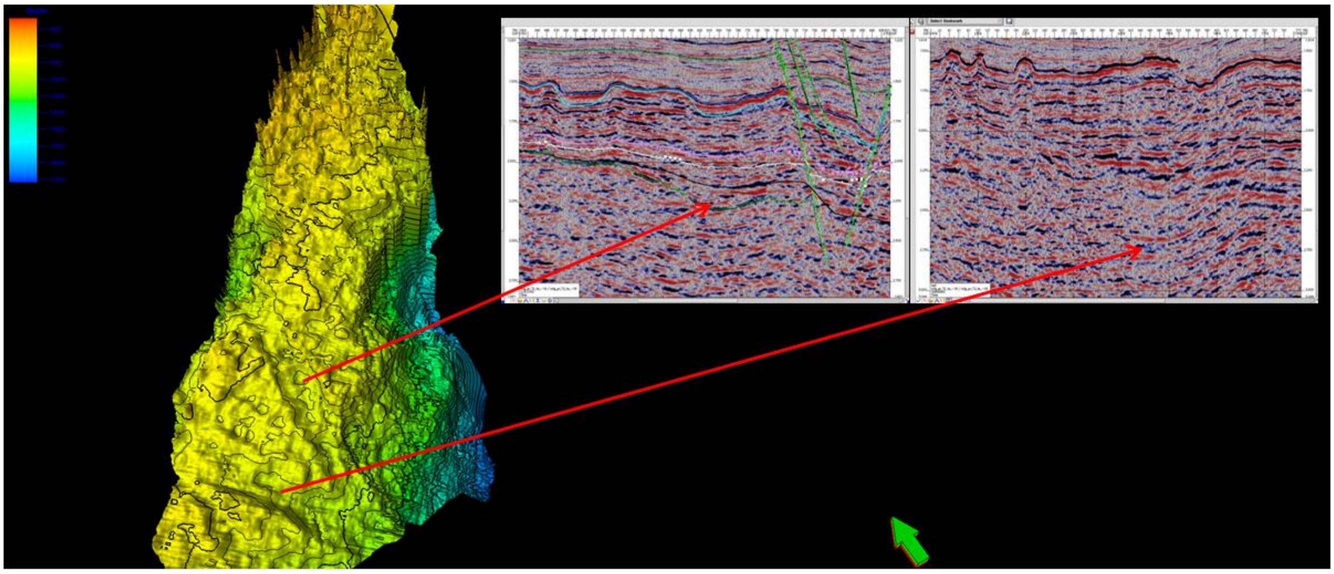


Figure 7 - Paleo-channel in southern area of JS-1 ridge

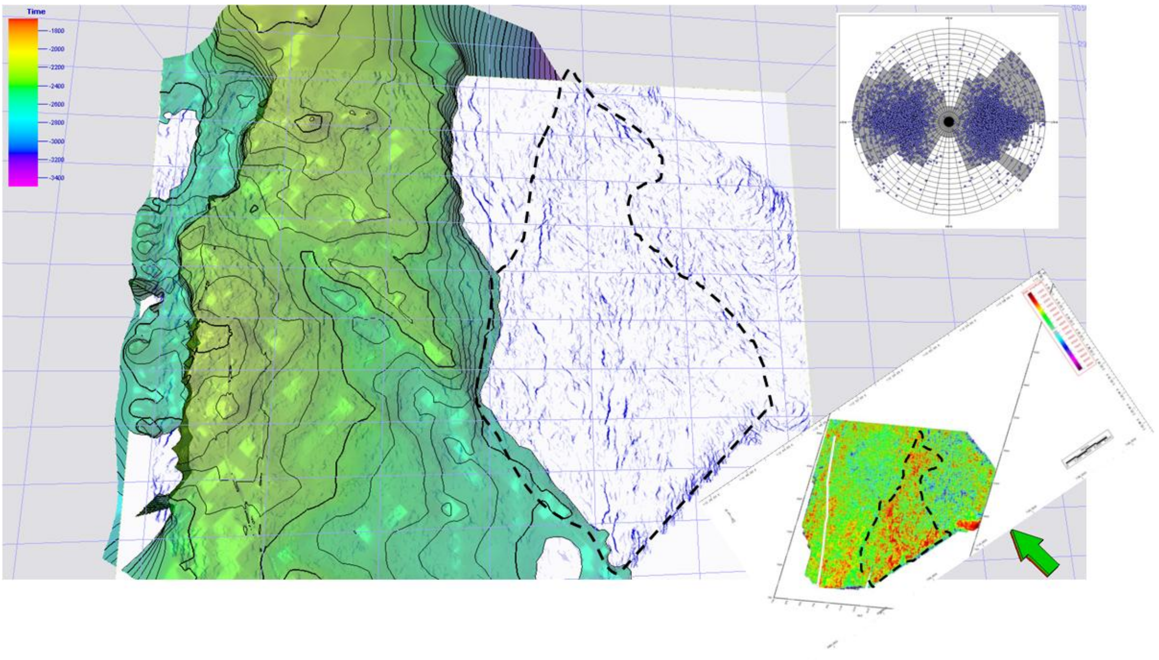


Figure 8 - Fracture analysis using ant-track (left) and Acoustic impedance map (right)

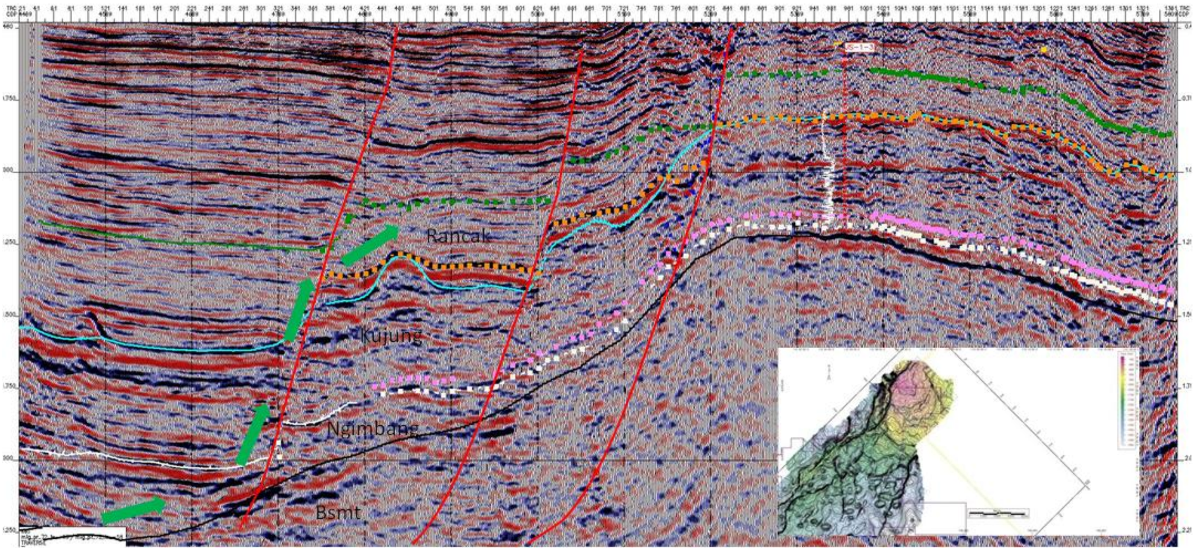


Figure 9 - Hydrocarbon migration scheme to post Kujung deposits