PROCEEDINGS, INDONESIAN PETROLEUM ASSOCIATION
Fortieth Annual Convention & Exhibition, May 2016

UNRAVEL THE OLIGOCENE-MIOCENE DEPOSITIONAL ARCHITECTURES IN THE NORTH MADURA PLATFORM USING SEISMIC STRATAL VOLUME

Fithra Harris Darmawan*
I Wayan Ardana**
Lee Chung Shen***
Aditya Kusuma Wijaya**

ABSTRACT

Various works on depositional setting and paleogeography of the Oligocene-Miocene sediments in East Java Basin have been done by previous authors using outcrop, well, and seismic data. The recent development in seismic technology has allow us to image the geomorphology or depositional features preserved in the stratigraphy record. An initiative has been taken to further understand the depositional architectures of the Oligocene-Miocene sediments in North Madura Platform using stratal volume method.

Detail horizon interpretations were conducted in the Oligocene-Miocene interval using the new reprocessed 3D seismic data in the study area. These horizons, given the definition of discordant or concordant surfaces, have been cross-checked and refined in the first pass of stratal volume, where distinct breaks and vertical shifts were observed due to cycle skip in initial interpretation. The intention for stratal slicing was to pick a depositional surface (geologic-time surface) so that any seismic attribute extracted on the particular surface could represent a genetic paleo-depositional unit, which result is 3D spatial transform of seismic volume into a 3D chronostratigraphic chart or Wheeler volume; an extension of concept for chronostratigraphic sequence analysis. This transformation considered the effects of 3D structure, different sediment deposition rates, horizon dip, and unconformity.

Five main intervals in the Oligocene-Miocene section were identified in this study. The stratal volume slice from these intervals able to show detailed geomorphic features such as fluvial channels and deltas. The interpretation of stratal slices was carried out to the five intervals by integrating all available geological and geophysical data, and using modern depositional and geomorphic models to guide the interpretation of depositional patterns in seismic-attribute slices.

INTRODUCTION

The East Java Basin is a proven prolific hydrocarbon province with oil and gas fields producing mostly from Tertiary reservoirs. The basin is considered as moderately to very mature basin with significant discoveries made in Oligocene to Miocene age reservoirs (e.g., Banyu Urip, Sukowati, Bukit Tua, and Jenggolo). Improving the understanding of depositional architectures of Oligocene-Miocene agesediments in the North Madura Platform is critical in predicting the distribution of potential reservoirs of this age, and finally this will lead to exploration success in the region.

The study area is located in The North Madura Platform, a stable basement high located between the Central Deep to the west and the North BD half-graben in the Madura Straits to the south. The region is dominated by several NE-trending basement highs and intervening half-grabens, that formed during the Tertiary period along the SE margin of the Sunda Plate (Manur and Barraclough, 1994). The Central Deep is a northeast - southwest oriented, asymmetrical, with a gently dipping, stable western flank. The North BD half-graben is a west - east direction extended from Western Madura Island to the Pagerungan half graben at the east. These two early Tertiary half-grabens are the principal hydrocarbon source containing a thick section of thermally mature lacustrine, coaly and marine shales.

The depositional setting and paleogeography of Oligocene-Miocone sediments in East Java Basin

*** PETRONAS Exploration International Ventures**
**** PETRONAS Carigali Indonesia**
***** CGG GeoSoftware**

have been studied in detail by various authors in the past, using outcrop, seismic, and well data (e.g., Ardhana 1993, Ruf et al. 2008, Posamentier et al. 2010, Rifki et al. 2014). The recent development in seismic technology brought a major change to seismic interpretation. 3D seismic data could give us the ability to spatially correlate interpretation of geology by making use of horizontal seismic resolution. Horizontal patterns of seismic attributes provide a unique benefit by linking the seismic signal directly to modern and ancient depositional models, improving seismic interpretation of petroleum systems and reservoirs (Zeng, 2010). This paper will apply seismic stratal volume method using 3D PSDM data available in the area with objective to reveal the detail geomorphology of Oligocene-Miocene sediments.

TECTONIC AND STRUCTURAL FRAMEWORK

Late Cretaceous-Paleocene Convergence (Subduction and Collision)

East Java Basin is located along the southeastern edge of Sundaland, part of Eurasia continent. Subduction of oceanic-oceanic crusts and oceanic crusts beneath continental blocks and Eurasia creton lead into collision of continental blocks and oceanic crust obduction (Figure 1). This resulted in NE-SW trending thrust-fold belts along sutures between the relatively rigid continental blocks involving mixed lithologies: sediments, meta-sediments, andesite, basalt, tuffs, gabro and ophiolite suites. Whereas the relatively stable continental blocks consists of granitic and metamorphic rocks.

Paleogene Divergence (Rifting)

Episodic rifting occurred mostly during the Eocene resulted in the formation of a series of half grabens, bounded by up-thrown ridges, trending northeast-southwest along the pre-existing thrust-fold belts or suture zones. On the other hand, the continental blocks remain relatively stable. The rifting episode was followed by major subsidence in the southern part of the basin during the Oligocene time. The rifting episodes was overlapped by a major subsidence along the southern part of the basin during the Oligocene time.

Neogene Convergence (Wrench and Basin Inversion)

Most of the earlier Neogene had been relatively stable until in about 7 Ma, when a major basin inversion and wrenching occurred and resulted in east-west trending structural elements. These include the relatively stable Northern Platform, the inverted and wrenched Central Uplift (RMKS), the deep Southern Basin, and the Kendeng Foldbelt. Most of the half grabens along and adjacent the RMK wrench zone have been inverted. Many east-west trending anticlines developed in the Southern Basin which have been reactivated episodically until today. These tectonic events are associated with subduction of Indian oceanic crust and Australian continental crust beneath Sunda Creton and formation of volcanic arc in the south.

STRATIGRAPHIC FRAMEWORK

The Tertiary sediments unconformably overly the pre-Tertiary sediments, meta-sediments, metamorphic rocks and igneous rocks.

The Tertiary stratigraphy of East Java Basin consists of a Regressive Mega Sequence in Paleogene-Early Miocene capped by a Major Maximum Flooding Surface in about 20 Ma and followed by a Transgressive Mega Sequence until today. These mega sequences seem to be associated with the extensional and compressional tectonic, respectively.The mega-sequences, in turn, consist of several sedimentary cycles bounded by maximum flooding and unconformity surfaces. Each sedimentary cycle, if complete, would ideally consists of regression followed by transgression characterized by an abrupt renewed clastic influx, gradually followed by clastic waning and finally capped by carbonate. Seismically it is marked by discordances including downlap, onlap and truncation.

Paleogene-Early Miocene Transgressive Mega-Sequence

The transgressive mega sequence consists of several sedimentary cycles: Ngimbang cycle, CD cycle, and Kujung cycle.

The Ngimbang cycle is an Eocene syn-rift sediments filling the half grabens and consists of fluvio deltaic sandstones, siltstones, claystones, shales and coals in the lower part gradually change to shallow marine shale in the upper part and capped by carbonate. In the southeastern part of the basin, equivalent deep water shales were deposited. Recent bio-stratigraphic work by Petronas integrated with well and seismic correlations revealed that the Ngimbang Cycle is actually consists of at least three sub-cycles each bounded by angular unconformities which indicate active and episodic rifting during the Eocene time.

The CD and Kujung Cycles marked a major subsidence in the southern part of the basin and the initial developments of a regional east-west trending shelf edge. They also marked a major transgression which lead to a major maximum flooding in the entire western Indonesia region. On the paleo-shelf in the north, the sedimentation is dominated by shallow marine limestones interbedded with shales in the lower part and thick platform carbonate with patch reef at the top. Barrier reefs grew along behind the shelf edge. Deep water shales, marls and thin limestones were deposited in the deep water slope and basinal area to the south with pinnacle reefs rising on the offshore highs or ridges. The top of the Kujung represent a major maximum flooding surfaces which ended the transgressive mega sequence.

Neogene-Recent Regressive Mega Sequence.

A major clastic influx over the extensive Kujung carbonate marked the onset of this regressive mega sequence which consists Tuban Cycle, Ngrayong Cycle, Wonocolo Cycle, Kawengan Cycle and Lidah Cycle. Tuban Cycle are mostly of fine grained shallow to deep marine sediment capped by carbonate which commonly known as Rancak formation.

Ngrayong Cycle is a sand-rich sediments deposited over the shale-rich Tuban Cycle. It consists of shallow marine to fluvio-deltaic sand-rich clastics capped by thin carbonates, widely deposited on the shelf in the north while equivalent deep marine turbidites, hemipelagic mudstones and contourites accumulated on the deep water slope and basin to the south. The distribution of sandy turbidites was largely controlled by paleo-topography. Coarser clastics were restricted to the low overlying Paleogene grabens, while the highs were by-passed by density currents and were consequently the sites of dominantly hemipelagic mud deposition.

Wonocolo Cycle are mostly of fine grained shallow to deep marine sediment, indicating a short back stepping of facies belts within the overall regressive mega sequence.

A major tectonic event creating the new east-west trending structural elements marked the onset of Kawengan Cycle in about 7 Ma. In the Northern Platform, moderate erosion occurred extensively east of Bawean Arc where Wonocolo cycle is completely eroded, while the Ngrayong cycle is partially to locally completely erode. Extensive platform carbonate with patch reef deposited above the unconformity. In the western part of the platform, no erosion observed but seismic and well indicate a south-easterly prograding clastics over the Wonocolo shales and carbonate. Major and deep erosion occurred along the Central Uplift (RMK Wrench Zone) where the erosion can be as deep as into the Kujung Cycle in places.

The erosional products were transported mainly into the deep Southern Basin, where many east-west trending anticlines were present. Sandy turbidides was deposited in the synclines while globigerina limestone were concentrated on the anticlines.Volcaniclastics were shed from the volcanic arc in the south.Reactivation of the structures followed by erosions and deposition turbidite, globigerina limestone and volcani-clastics was episodically occurring during the Late Neogene to recent.

METHODOLOGY

3D seismic stratal volume were created using Domain Transform technique in the study area. Hammon and Dorn (Hammon et al., 2008; Dorn et al., 2008; Dorn, 2011a; Dorn 2011b) have introduced a workflow to remove the three-dimensional effects of structure from 3D seismic volumes called Domain Transform. The interpretation-guided workflow removes the structural deformation from a seismic volume and interprets in stratigraphy domain. It improves the imaging of paleo-depositional systems by creating a volume consists of surfaces that could be picked as paleo-depositional surfaces (geologic-time surfaces). This stratal volume could be used to image and interpret the seismic geomorphology and stratigraphy since each horizontal slice approximately represents a paleo-depositional surface. With key sequences boundaries being defined, it can be representing a 3D Wheeler volume.

The Domain Transform uses interpreted structural surfaces as a starting guide to create a three-dimensional spatial transformation (Dorn, 2011). It includes algorithms to handle the effects of differential sedimentation and compaction, faults, folds, horizon dip, unconformities (including angular unconformities), and other discordant surfaces. Once the volume displacement is calculated for a specific set of input surfaces, the 3D transformation matrix can be stored and used to transform collocated volumes, surfaces, well paths, well logs, formation tops, data which represented in the 3D sampling space to which the transformation applies (Dorn, 2013). The transformation matrix then could be utilized to inverse transform the data from stratal domain back to structural domain. Interpretation such as geological features in horizon or 3D mesh format can be transformed back for further analysis.

RESULT

Five main surfaces were interpreted from the Oligocene-Miocene section which comprise of, from oldest to youngest, Top CD Carbonates, Top Kujung, Top Tuban, Top Ngrayong, and Top Wonocolo (Figure 4). These horizons, given the definition of discordant or concordant surfaces, have been cross-checked and refined in the first pass of stratal volume, where distinct breaks and vertical shifts were observed due to cycle skip in initial interpretation. Three main interval were identified later to be transformed to stratal domain to further understand the depositional architecture within each interval.

Kujung Interval

The Kujung Formation is the most important hydrocarbon reservoir in the East Java basin (Petroleum Report of Indonesia, 2002). It overlies the Ngimbang Formation and, in some localities, rests unconformably over the basement (Ardhana et al., 1993).The Kujung Formation was divided into three units, from the eldest to the youngest as Kujung unit III, II, and I. Kujung unit III is a clastic-rich regressive sequence with thickness ranging from tens to thousands feet across East Java Basin. Kujung unit II consists of a transgressive sequence of shallow water carbonates and calcareous shales with localized carbonate build-ups over high areas. Kujung II and Kujung III unit were characterized by discontinuous and irregular seismic events in the study area. This could indicate high lateral sedimentary facies variation in this interval. In the Early Miocene most of the region in the North Madura Platform experienced carbonate sedimentation depositing Kujung I unit. High-energy clean limestone and common reef build-ups developed during this time.

Domain Transform was performed from Top Kujung I to Top CD Carbonate interval,covering Kujung I and II unit. The stratal slice in the Kujung II interval shows abundant development of small patch reefs in the northern part of the North Madura Platform with development of shelf-margin reef towards the south. These patch reefs are uniformly small with diameter commonly less than 300 m. During the later stage of Kujung II time these buildups became more isolated and increasing in size. As we go shallower or younger, carbonate mound facies is started to develop in the North Madura Platform with channels running in between the reef complex. This marked the deposition of Kujung I unit that characterized by a continuation of nearly circular buildups in the northern part of study area. The seismic time slice and stratal slice comparison from this interval shows that the east-west trending channel could not be seen from time slice (Figure 5). However, the stratal slice is able to resolve this channel.

Tuban Interval

In the Early Miocene times, starting from about 20 Ma, a new sediment source coming from the north and Tuban claystone began to cover the Kujung Formation. In the North Madura Platform Tuban Formation is deposited in the shallow shelf setting and is getting deeper to the southern part of North Madura Platform. During Oligocene-Miocene time the platform remain stable and it allows rapid shift from lowstand to highstand system tract during relative sea level changes. Stratal slicing result in this interval shows development of meandering channel with relatively north-south direction at the end stage of Tuban deposition (Figure 7). This suggested that during this time the North Madura Platform was exposed and the channel started to incise this area. The comparison between seismic time slice and stratal time slice was performed to demonstrate how stratal slicing could image the meandering channel despite the Wonocolo channel effect that affecting the Tuban interval.

Ngrayong Interval

The progradation of clastics from the north that started approximately on 20 Ma continued to about 5 Ma and coarsened upwards into the Ngrayong Formation. Ngrayong Formation is a sand-rich sediments overlying the shales and limestones of Tuban Formation. These sands prograded south to the paleo-shelf-edge of the Kujung carbonate. Ngrayong Formation is widely deposited in the North Madura Platform as shallow marine to fluvio-deltaic sand-rich clastics. The stratal slicing performed in this interval is able to reveal the north-south trending delta that aligned with regional understanding of Ngrayong depositional environment. The delta having 5 km-wide delta lobe with 500 m-wide channel running north-south.

Figure 8 shows how the stratal slicing able to image the stratigraphic features below the Wonocolo effect.

CONCLUSION

The seismic stratal slice created using Domain Transform workflow in the study area is able to improve the imaging of paleo-depositional systems within three intervals: Kujung, Tuban, and Ngrayong interval. These stratal slices enabled us to interpret the seismic geomorphology and paleo-depositional system within each interval. The stratal slice from Kujung interval shows abundant development of small patch reefs at the lower part of Kujung that gradually grow into bigger buildups towards the end of Kujung time. While in Tuban interval, the stratal slice suggested the area was exposed at the end stage of Tuban time that indicated by northeast-southwest meandering channel direction. In Ngrayong interval, stratal slicing is able to reveal the north-south trending delta below the Wonocolo effect. The interpretation results from seismic stratal slice are consistent with the regional understanding on stratigraphy and depositional environment of each interval. Further work needs to be done to refine the study by integrating available well, core, and seismic inversion data to fully understand and model the facies distribution of each interval in detail.

ACKNOWLEDGEMENT

The authors wish to thank the management of PETRONAS and Indonesia Host Authority (SKK MIGAS & MIGAS) for their approval to publish this paper. We would like also to thank to CGG Geosoftware for providing the license and technical support to us. And we thank all of those who have helped us while in Malaysia and Indonesia by giving us the guidance, ideas, as well as assistance in preparing this presentation material.

REFERENCES

Ardhana, W., 1993, A Depositional Model for The Early Middle Miocene Ngrayong Formation and Implications for Exploration in The East Java Basin, Proceedings lndonesian Petroleum Association, Twenty Second Annual Convention, v. 1, p. 395-443.

Bransden, P.J.E., and S.J. Matthews, 1992. Structural and Stratigraphic Evolution of the East Java Sea, Indonesia, Proceedings lndonesian Petroleum Association, 21st Annual Convention, v. 1, p. 418-453.

Dorn, G. A., 2013, Domain transform: A tool for imaging and interpreting geomorphology and stratigraphy in seismic volumes, The Leading Edge, p. 146-153.

Dorn, G. A., 2011, Interpretation workflows enabled by a Domain Transform, First Break, v. 29, p. 99-108.

Johansen, K.B., 2003, Depositional geometries and hydrocarbon potential within Kujung carbonates along the North Madura platform, as revealed by 3D and 2D seismic data, Proceedings Indonesian Petroleum Association, IPA03-G-174.

Kenyon, C. S., 1977, Distribution and Morphology of Early Miocene Reefs, East Java Sea, Proceedings lndonesian Petroleum Association, Sixth Annual Convention.

Manur, H. and R. Barraclough, 1994. Structural control on hydrocarbon habitat in the Bawean area, East Java Sea. Proceedings of the Indonesian Petroleum Association, 23rd Annual Convention, v. 1, p.128-144.

Mudjiono, R., and G.E. Pireno, 2001. Exploration of the North Madura Platform, offshore East Java, Indonesia. Proceedings of the Indonesian Petroleum Association, 28th Annual Convention, v.1, p.707-726.

Posamentier, H. W., Laurin, P., Warmath, A., Purnama, M., Drajat, D., 2010, Seismic Stratigraphy and Geomorphology of Oligocence to Miocene Carbonate Buildups, Offshore Madura, Indonesia, Cenozoic Carbonate System of Australasia, SEPM Special Publication, v. 95, p. 175-192.

Rifqi, M. A., Armia, A. P., Nugraha, A., Fajar, M., Prasetyo, A., 2014, Seismic Facies Analysis of Turbidite Complex in Ngrayong Formation, East Tuban Area, East Java Basin, Indonesia, Proceedings lndonesian Petroleum Association, Thirty-Eight Annual Convention.

Ruf, A. S., Simo, J. A., and Hughes, T. M., 2008, Insight on Oligocene-Miocene Carbonate Mound Morphology and Evolution from 3D Seismic Data, East Java Basin, Indonesia, Proceedings lndonesian Petroleum Association, Thirty-Second Annual Convention.

Satyana, A. H., and Djumlati, M., 2003, Oligo-Miocene Carbonates of the East Java Basin, Indonesia: Facies Definition Leading to Recent

Significant Discoveries, AAPG International Conference, abstracts and programs.

Sharaf, E., Simo, J.A.T., Carroll, A.R. and Shield, M., 2005, Stratigraphic evolution of OligoceneMiocene carbonates and siliciclastics, East Java Basin, Indonesia, American Association of Petroleum Geologists Bull, v. 89, p. 799-819.

Zeng, H., 2010, Stratal slicing: Benefits and challenges, The Leading Edge, p. 1040-1047.

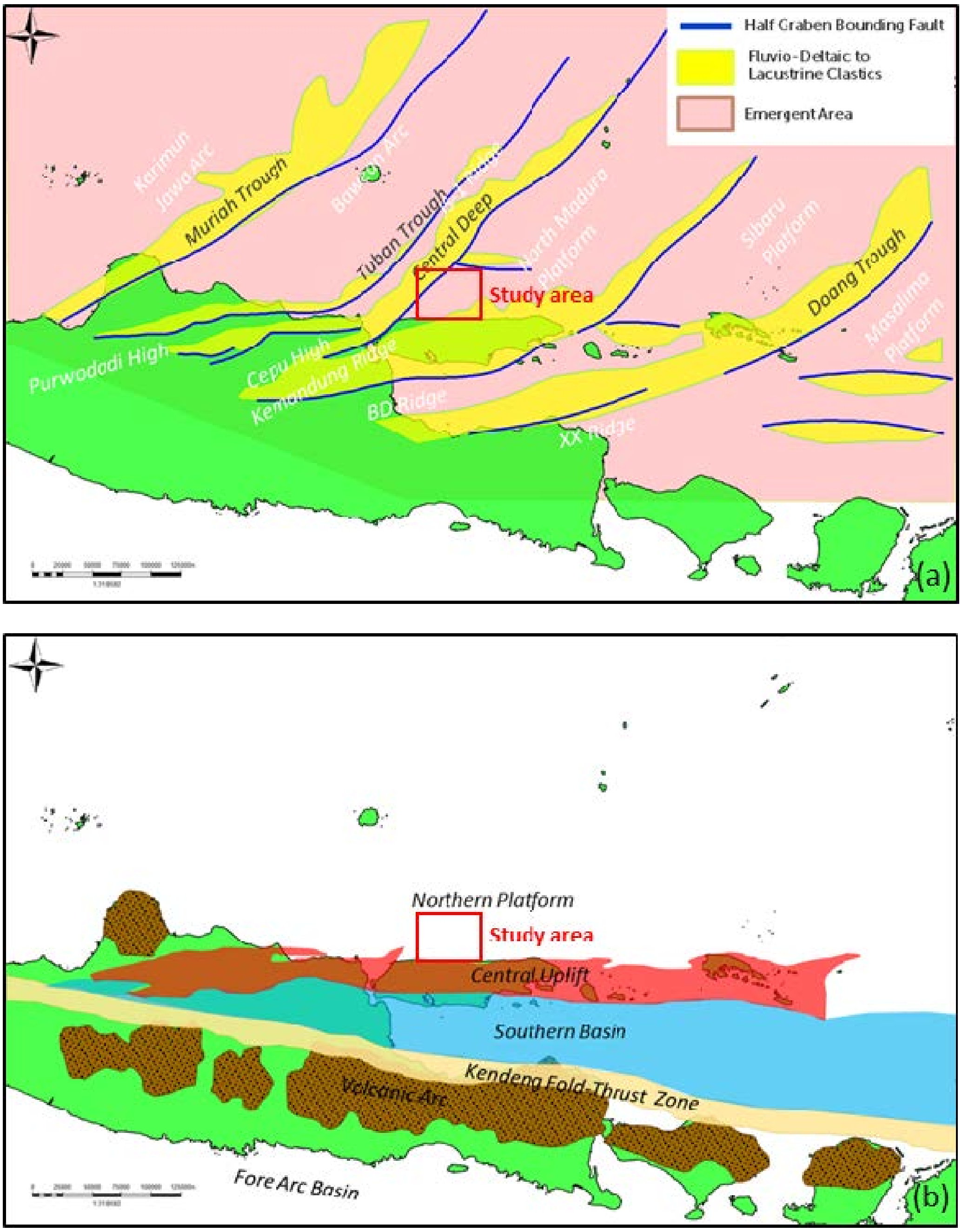

Figure 1 - Tectonic setting of East Java Basin. Figure (a) shows Paleogene structural framework of East Java Basin and (b) shows the Neogene structural framework of East Java Basin. Study area located in the North Madura Platform, a stable basement high located between the Central Deep to the west and the North BD half-graben in the Madura Straits to the south.

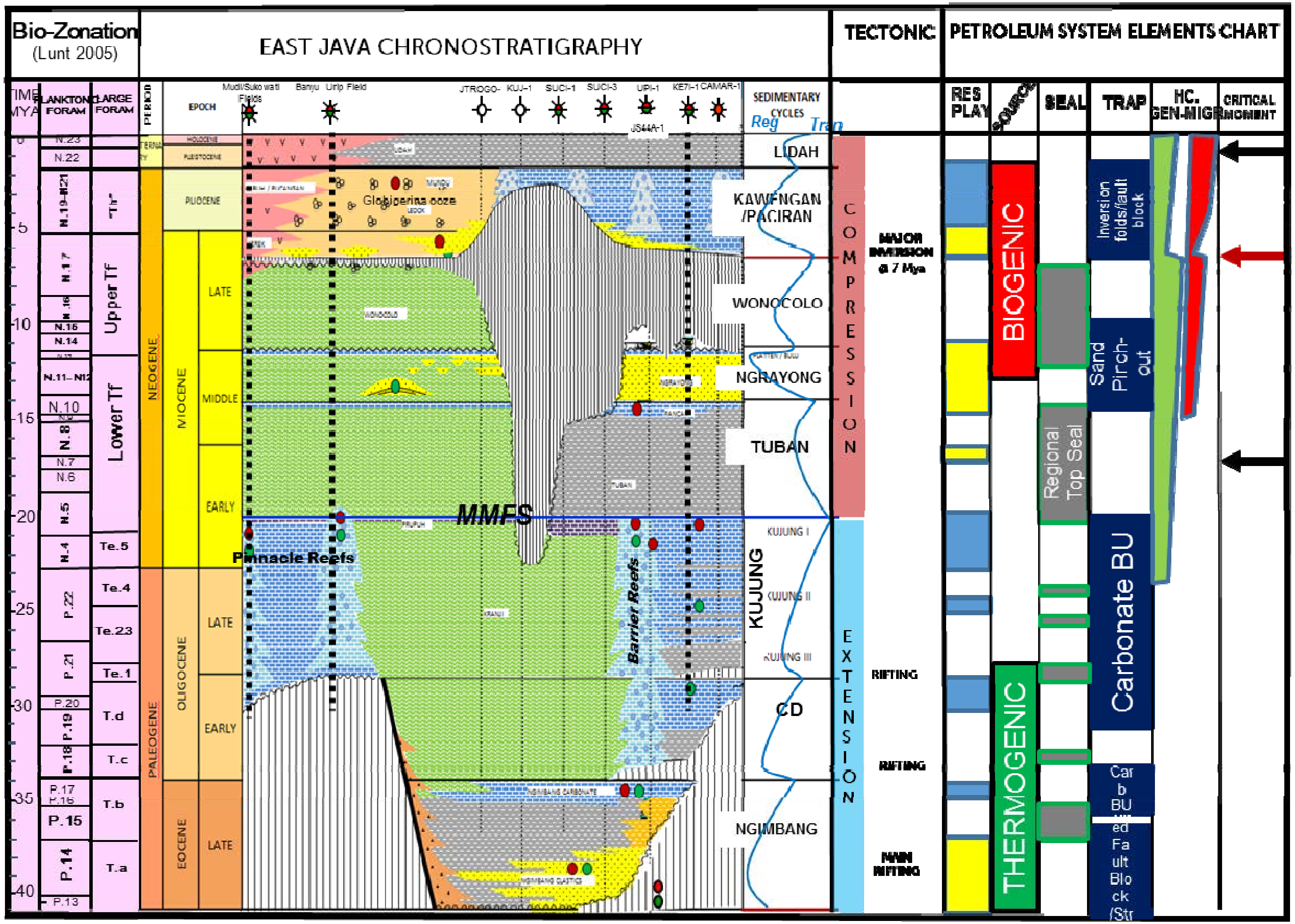

Figure 2 - East Java Chronostratigraphy and Petroleum System Chart (modified after Setiawan, 2014).

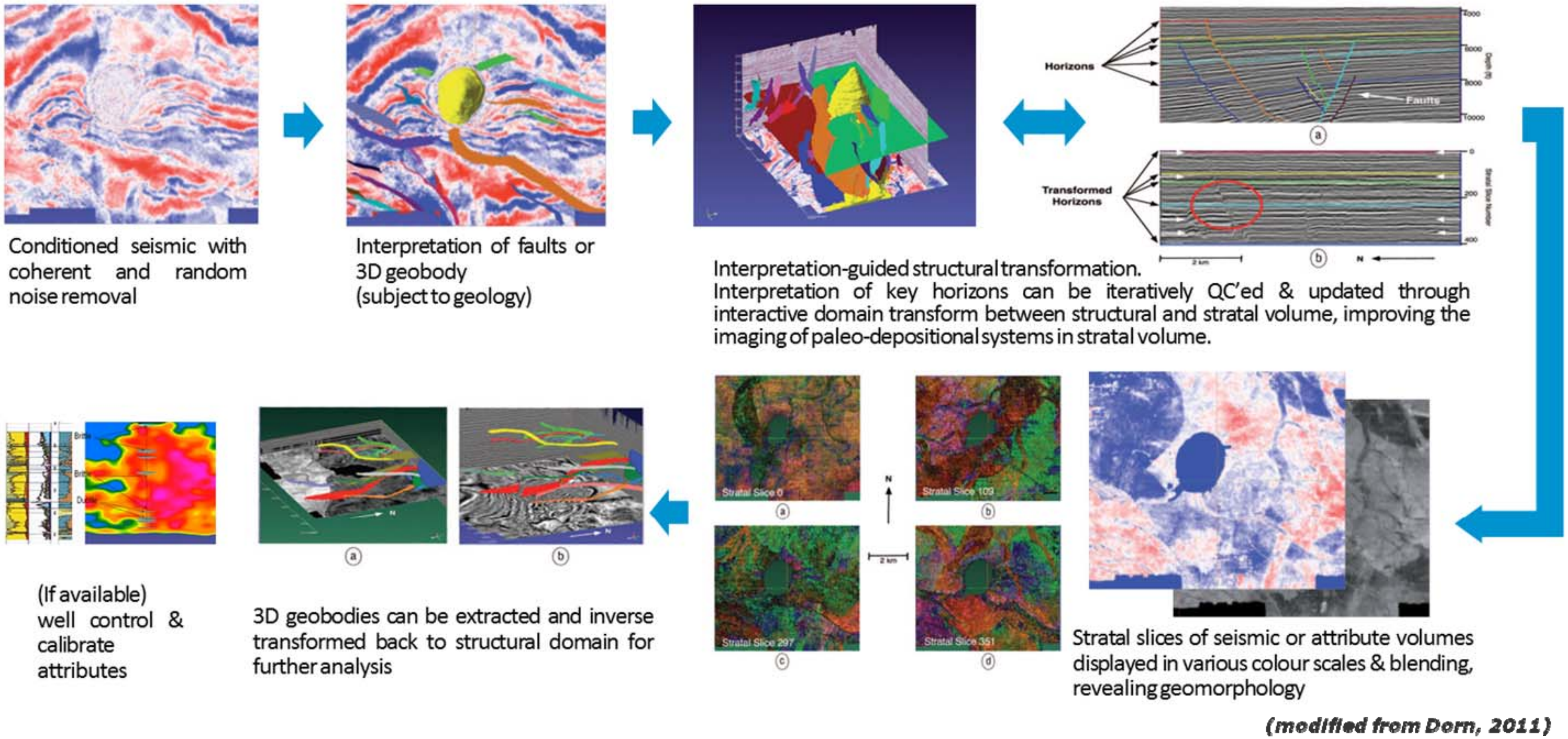

Figure 3 - Domain Transform workflow diagram introduced by Hammon and Dorn (Hammon et al., 2008; Dorn et al., 2008; Dorn, 2011a; Dorn 2011b), to remove the three-dimensional effects of structure from 3D seismic volumes.

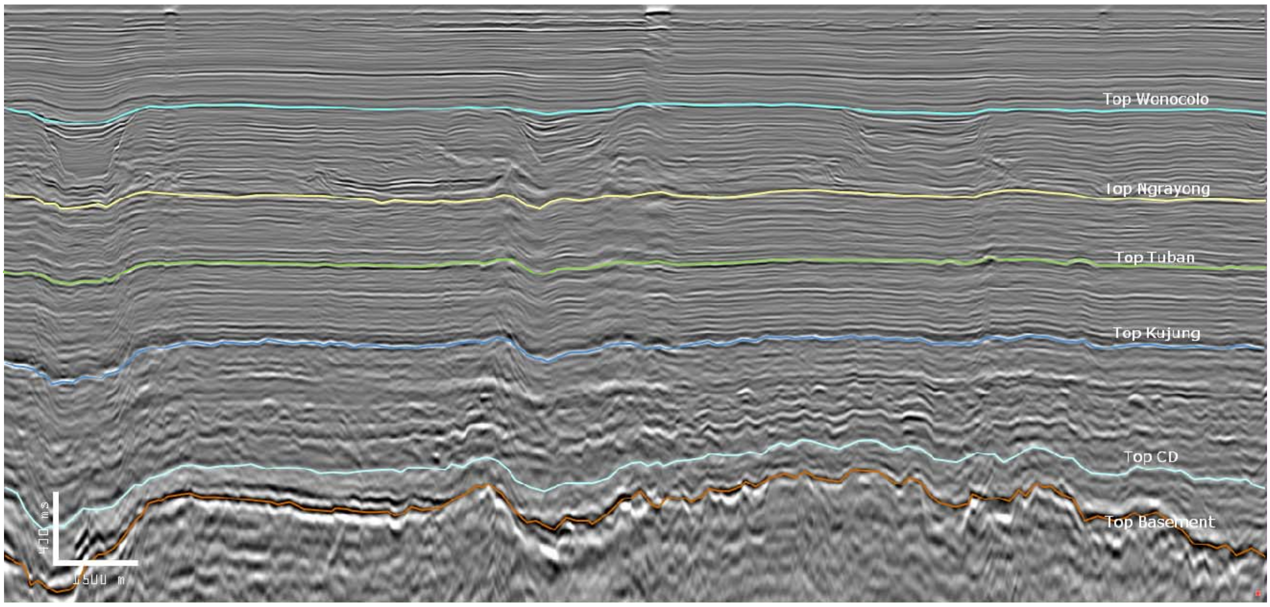

Figure 4 - Seismic cross section showing seismic interpretation of five main surfaces from the Oligocene-Miocene section which comprise of, from oldest to youngest, Top CD Carbonates, Top Kujung, Top Tuban, Top Ngrayong, and Top Wonocolo.

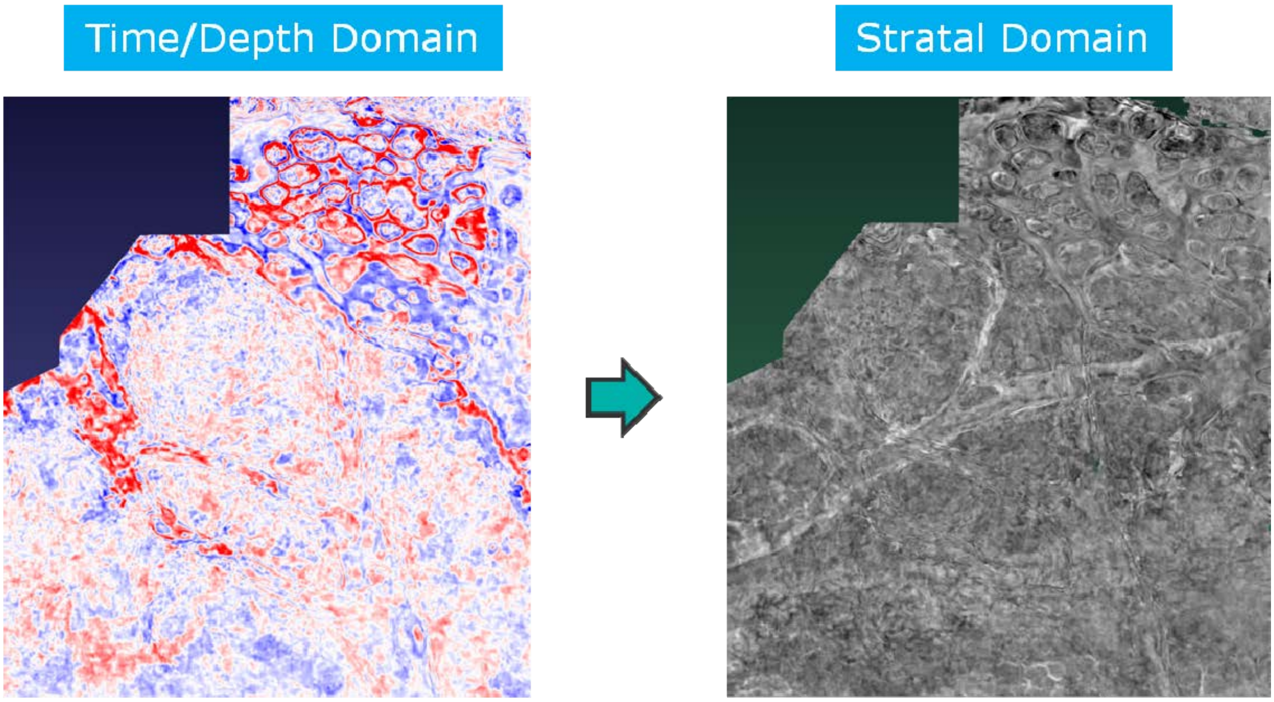

Figure 5 - The seismic time slice and stratal slice comparison from Kujung interval. Seismic stratal slice is able to image the east-west trending channel that could not be seen from seismic time slice at approximately the same level.

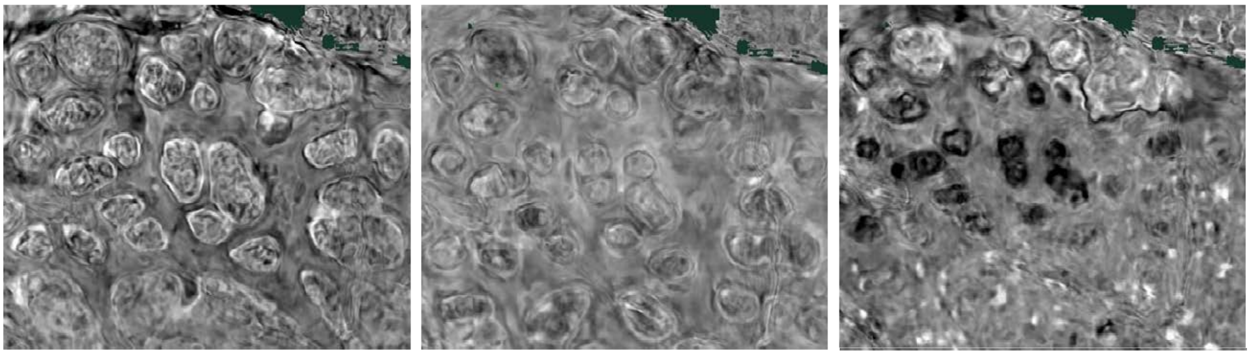

Figure 6 - Stratal time slice at Kujung interval showing the development of smaller patch reefs in Kujung II unit to bigger and nearly circular Kujung I unit (from right to left).

Figure 7 - Stratal slicing result in Tuban interval showing development of meandering channel with relatively north-south direction at the end stage of Tuban deposition.

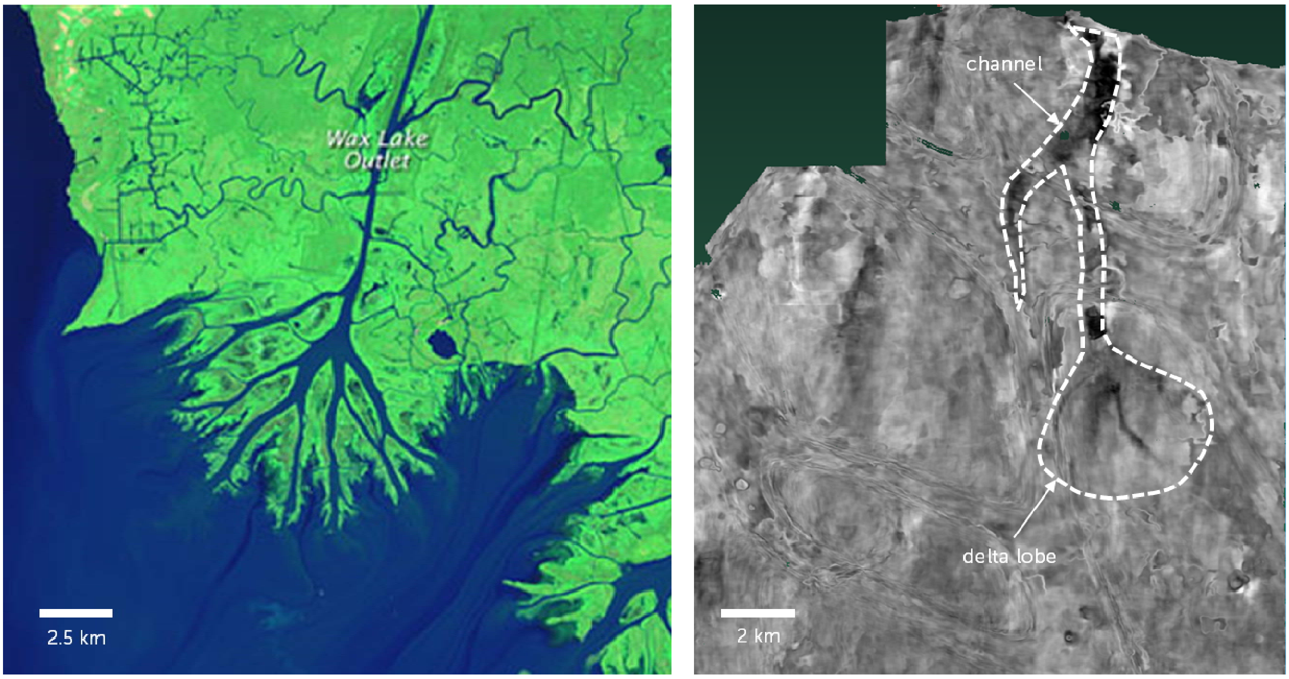

Figure 8 - The stratal slicing performed in Ngrayong interval is able to reveal the north-south trending delta below the Wonocolo effect, which aligned with regional understanding of Ngrayong depositional environment. The delta having 5 km-wide delta lobe with 500 m-wide channel running north-south.