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Seismic and Sequence Analysis of Middle to Late Miocene Deposits of Northeast Java Basin

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Abstract - This study is focused on Middle to Late Miocene sediments. As depicted in the regional geology of Indonesia, the area of study is part of Northeast Java Basin. There are three phases of tectonism in the basin: extensional tectonics at Eocene-Oligocene time, compressional tectonics at Middle Miocene, and compressional tectonics at Miocene-Pliocene time. The result of the study shows three sequences were developing during Middle to Late Miocene, those are: (1) Middle Miocene sequence-1 (MM-1 sequence) consisting of a Lowstand Tract System deposition in Middle Miocene-1 (LST MM-1), Transgressive System Tract deposition in Middle Miocene-1 (TST MM-1), and Highstand System Tract deposition in Middle Miocene-1 (HST MT-2); (2) Middle Miocene sequence-2 (MT-2 sequence), comprising Transgressive System Tract Middle Miocene-1 (TST MM-2), and Highstand System Tract deposition in Middle Miocene-1 (HST MM-2); (3) Late Miocene sequence-1 (LM-1 sequence), composed of a Lowstand Tract System deposition in Late Miocene -1 (LST LM-1) and a Transgressive System Tract deposition in Late Miocene-1 (TST LM-1).

Keywords: Java Basin, Miocene deposits, seismic, sequence stratigraphy

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Introduction

Background

Sequence stratigraphy is one of the main concepts in hydrocarbon exploration by means of predictive analysis in sediment packages. This method is very useful for identifying potential reservoir rock with a stratigraphic trap. It can also show pitfalls in the structural traps formed in the basin. This method helps the exploration effort for a new hydrocarbon accumulation, field development, and reserve estimation. This article shows an application of sequence stratigraphy in NE Java Basin. The Northeast Java Basin is one of the sedimentary basins in Indonesia (Figure 1), which has a great hydrocarbon potential. According to Martodjojo (1978), this basin is located in an area surrounded by five sedimentation regimes: stable-shelf continent (Rembang Zone), transition zone (Randublatung Zone), unstable marine basin (Kendeng Zone), volcanic zone, and southern continental shelf (southern mountains). The Northeast Java Basin was the result of a collision between the Sunda Microplate and the Indian Plate. The tectonic position of the Northeast Java Basin is located on the back-arc basin formed in the Early Tertiary subduction-related process in Java.

According to Tucker (1982), the analysis of sequence stratigraphy can be done through several methods, including seismic and biostratigraphic analysis.

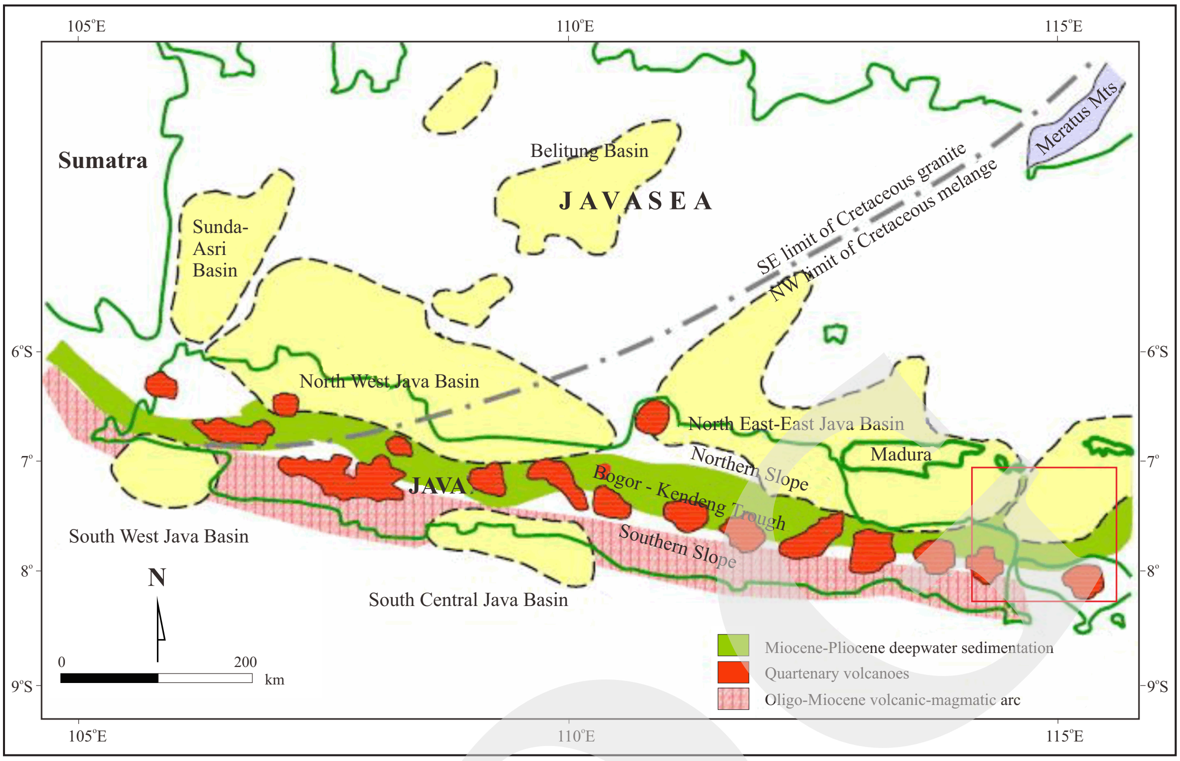

Figure 1. Locality map of the researched area (red square).

Seismic stratigraphy is a stratigraphic interpretation based on data from seismic reflection. Some characters appear in every seismic section which helps in explaining the stratigraphy of an area. In this setting, seismic data can be integrated with biostratigraphic data, which identify the depositional age and depositional environment occuring in the system.

Based on the above mentioned, a study has been conducted based on the seismic data integrated with well data on the sequence stratigraphy of sediments in the Middle to Late Miocene time in the Madura Strait region, part of the Northeast Java Basin.

Sequence Stratigraphy

System Tract of Sequence Stratigraphy

System tract is a contact between deposits of similar ages (Posamentier, *in* Walker and James, 1992). The timing is based on biostratigraphy. The system tract boundaries are identified and correlated based on discontinuities. All of discontinuities are the result of fluctuations in a relative sea level.

Referring to the concept of depositional sequence proposed by Walker and James (1992), there are four types of system tracts: Low-Stand System Tract (LST), Transgressive System Tract (TST), High-Stand System Tract (HST), and Shelf Margin System Tract (SMST). The presence of each system tract is dependent on the type of sequence boundary. If a deposition forms the type 1 sequence, then the system contains the LST, TST, and HST. The type 1 sequence boundary implies that the resulting system tract has been influenced by sea level changes to achieve reduction in a shelf break. Type 2 sequence contains SMST, TST, and HST. The system tracts of this type is the result of decreasing relative sea level fall, that does not reach a shelf break.

Depositional Sequence Analysis

The depositional sequence is basically determined by objective criteria such as the relationship between the physical layers, so that the concept is very useful for the development of a regional stratigraphic framework. This concept is not affected by the amount of rock-type determinations, fossils, depositional processes, and other criteria which are generally subjective and varieted (varied?) throughout the sequence itself.

Sangree et al. (1993) described several types of seismic reflection terminations:

- Onlap is the termination for strata that were initially tilted. Onlap is usually seen at the base of a depositional sequence and can indicate a sequence boundary.
- Marine onlap is a condition where progressive marine strata onlap toward the mainland or to an elevated topography on the basin.
- Coastal onlap is terminated for progressive coastal deposition toward the mainland.
- Downlap is where younger layers prograde over the older ones.
- Toplap represents positions initially tilted up against younger covering layers.
- Erosional truncation is the condition where the upper part of older layers are angled to younger ones.

East Java Sedimentation Regime

As mentioned in the Introduction part, Martodjojo (1978) divided East Java into five sedimentation regimes from north to south: stable-shelf continent (Rembang Zone), transition zone (Randublatung Zone), unstable marine basin (Kendeng Zone), volcanic zone, and south continental shelf (southern mountains). According to Martodjojo (1978), the Rembang Zone crosses through the northern boundary of Java Island which is detached from the Randublatung Zone by Lusi River on the west, Kening River on the east, and Solo River on the east. Sandstone and carbonates intercalated with marl and claystone are common in these areas, which had been deposited on the continental shelf.

The region of Randublatung Zone had been determined by Bemmelen (1949) including the Blora-Cepu Hills and Ngimbang-Dander Hills. This zone is dominated by marl and claystone with sandstone, calcarenite, and carbonate interbeds that act as important reservoirs. Those sediments are interpreted to be deposited on an undulated-continental slope. Bemmelen (1949) also described that the Kendeng Zone was dominated by volcanoclastics and marls with some claystone, sandstone, and carbonate interbeds, that were derived from deep ocean basin deposits. Fine sediments are more abundant than coarse material, and can act as reservoirs. The rate of the deposition is very rapid and may be greater than the rate of the subsidence.

Depositional Sequence of Northeast Java Basin

Stratigraphically, the Northeast Java Basin can be divided into three major depositional sequences, those are the Eocene-Early Oligocene sequence, the Late Oligocene-Miocene sequence, and Plio-Pleistocene sequence (Kusumastuti *et al.*, 1999). The Early Eocene-Oligocene sequence is associated with the rifting phase containing both clastic and carbonate sediments. The Eocene clastics were deposited in river environments, including freshwater lakes (lacustrine). The primary source material forming hydrocarbons occurred in those environments.

The Late Oligocene-Miocene sequences are separated by a regional unconformity beneath the cover sequence with ENE-WSW orientation. They occured as carbonate shelf deposits formed during the Late Oligocene known as Prupuh Formation followed by the formation of Early Miocene reef limestones. During the Middle to Late Miocene, the presence of a relatively large supply of sediment coming from the north and south of the basin led to the cessation of the carbonate deposition. The deposition of the volcanoclastics overlies most of the southern basin, distributed from the northern part of Java to the recent Madura Coast.

The Plio-Pleistocene sequences were unconformably deposited on the Late Oligocene to Early Miocene sequence, that in some places were eroded throughout the Middle-Late Miocene sequence. The sedimentation sequence, in the studied area, was commenced from the eastern part of the basin occurring as limestone of the

Paciran Formation and marl of the Kalibeng Formation in the western part of the basin. The Paciran Formation comprises limestone rich-in pelagic Globigerina of which westwardly the Globigerina content increases throughout the marl of Kalibeng Formation.

The deposition of Paciran Formation and Kalibeng Formation was followed by the prograding-wedge sediments of the Pucangan and Lidah Formations. The Pucangan Formation consists of volcanoclastic sediments derived from the volcanic belt in the southern part of the basin, whilst the Lidah Formation is equivalent to the marine sediments of the Pucangan Formation containing marine shale and limestone debris (detritus) from limestones that formed earlier. This formation is distributed widely in the Kendeng Zone. In the stratigraphy of Madura Strait, the Pucangan Formation has different facies with Sonde Formation (Kusumastuti *et al*., 1999). At the end of the Plio-Pleistocene to Recent, terrestrial sediments (nonmarine) were deposited as the Kabuh Formation and Notopuro Formation.

Methods

The objective of the study is to determine the Middle to Late Miocene sequence in Northeast Java Basin, located in Madura Strait Region, then to conduct analyses of the sedimentation packets. After that, to place them into a sequence stratigraphic framework. In the analysis, the seismic stratigraphic method was applied supported by biostratigraphy and well-log data that are available for this research. The data were taken from Balawan, located in the eastern part of the studied area, and Flint well, situated in the western part of the studied area. The two wells partially penetrated the analyzed sedimentary packages. The distributions of the system tracts can be observed by seismic trajectory controlled by the well-log data. The biostratigraphy data in this study is primary data needed for determining the age of the horizon analyzed. The biostratigraphic data were provided and analyzed by the LEMIGAS (Lembaga Minyak dan Gas Bumi/ Research and Development Centre for Oil and Gas) together with several reports from other companies. The data were used for determining age boundaries (horizon) of Early Miocene to Late Miocene, and then they were tied to the seismic data.

Results and Discussion

Middle Miocene-1 Sequence (MM-1 Sequence)

This sequence was deposited as the type-1 sequence in the late Early Miocene sediment intervals. This sequence thins mainly to the southwest and onlap on the unconformity. The Middle Miocene-1 sequence (MM-1 sequence) is composed of Lowstand System Tract deposition in Middle Miocene-1 (LST MM-1), Transgressive System Tract deposition in Middle Miocene-1 (TST MM-1), and Highstand System Tract deposition in Miocene Middle-1 (HST MM-1).

This system tract was deposited above the Early Miocene sediments. The deposition of the Lowstand System Tract in Middle Miocene-1 (LST MM-1) occured when the sea level receeded faster than the subsidence of the basin. The rapid drop of the sea level led to the development of downlap patterns (Figure 2), while on seismic AD-7 it shows the patterns of onlap, which describes the lowstand deposition process that continues until the sediment supply no longer could keep pace with the accommodation continue to be formed by the subsequent rise in the sea level. These show that the lowstand deposition process continued until the sediment supply no longer could keep pace with accommodation by the subsequent rise in the sea level.

The dispersal of the Lowstand System Tracts deposition in Middle Miocene-1 (LST MM-1) occured only in places. The deposition of this system tract only occupied lowerlying areas at the late Early Miocene structuring limited by elevation in the eastern part with relative growth to the south-west (SW) and north-east (NE). In general, the internal configuration of the seis-

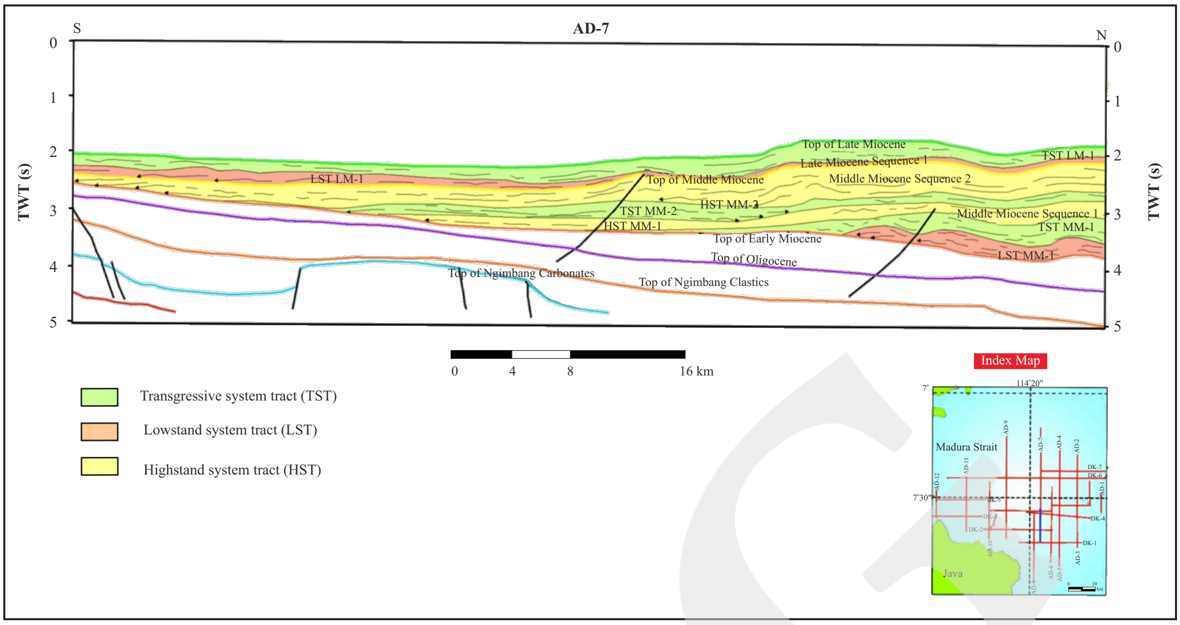

Figure 2. Interpretation of seismic line AD-7.

mic interpreted of the lowstand system tracts shows parallel and subparallel positions. From the distribution pattern, it is estimated that the sediments were accumulated in the lower areas, extending east-west of the structure formed on the top of the Early Miocene sediments. These structures which shaped the basin, were formed by the remnants of a tectonic activity which well developed during the Cretaceous to Middle Eocene epoch. According to Martodjojo (1978), the Rembang Zone crosses through the northern boundary of Java Island which is detached from the Randublatung Zone by Lusi River on the west, Kening River on the east, and Solo River in the south. Sandstone and carbonates intercalated with marl and claystone are common in these areas, which had been deposited in a continental shelf.

The deposition of the Transgressive System Tract Middle Miocene-1 was preceeded by a rise in the sea level that inundated almost the entire shelf area previously exposed by the sea level fall. The spreading pattern of the Transgressive System Tracts deposition in Middle Miocene-1 (TST MM-1) occupied a slightly wider area than the spread pattern of Lowstand System Tract deposition in Middle Miocene-1 (LST MM-1). This was caused by the addition of accomodation space for sediment accumulating by a relative sea level rise. The seismic onlap patterns indicate that the sea level rise accompanied this Low Stand System tract deposition system (Figure 3). Its distributin shows that the Transgressive System Tract deposition in Middle Miocene-1 (TST MM-1) experienced thinning towards the elevation to the north and south.

The Highstand System Tract deposition in the Middle Miocene-1 (HST MM-1) began to form when sea levels rose slowly as sediment supply continued to grow. This condition raises the patterns downlap on seismic AD-7 (Figure 2). In general, the internal configuration of interpreted seismic of the lowstand system tract shows parallel and subparallel patterns. The spread of the Highstand System Tract deposition in Middle Miocene-1 (HST MM-1) continued to occupy the same system tract deposition limited by elevations in the north and south peaks formed by the Early Miocene sediments (Figure 3). In general, the Highstand System Tract deposition in the Middle Miocene-1 (HST MM-1) had thinned in the range 0.0-0.1 second on parts of the boundary deposition, especially to the west, east, and south-west (Figure 4). The HST MM-1 sediment

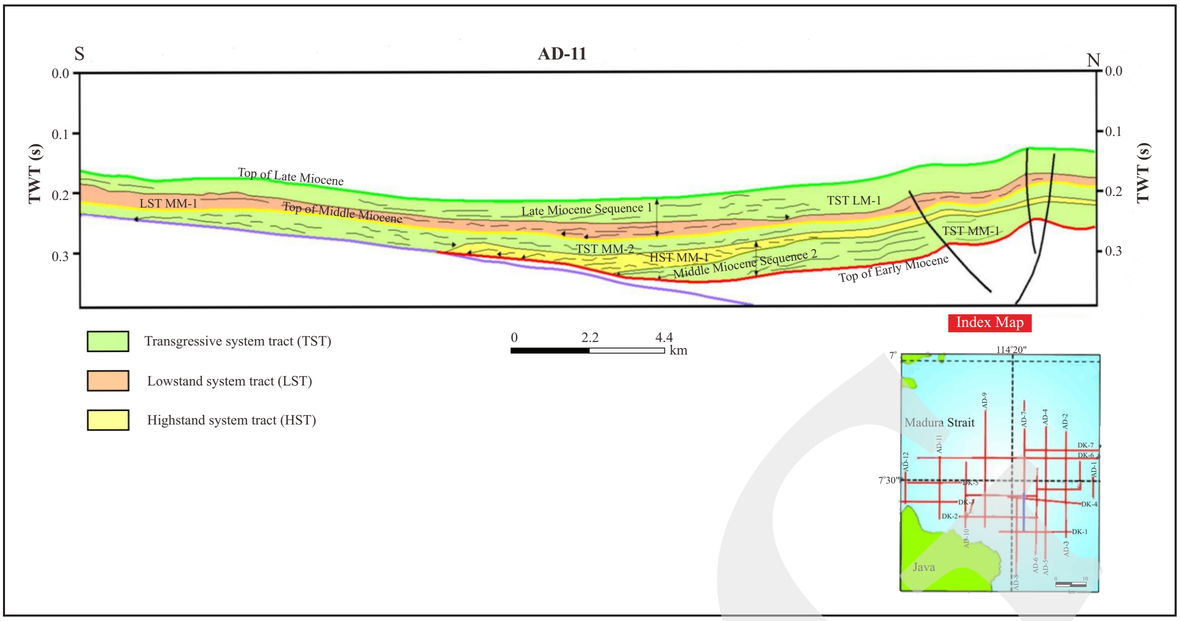

Figure 3. Section of onlap TST MM-1 to the peak of Early Miocene deposition (orange horizon) at seismic line AD-11 showing rising of sea level.

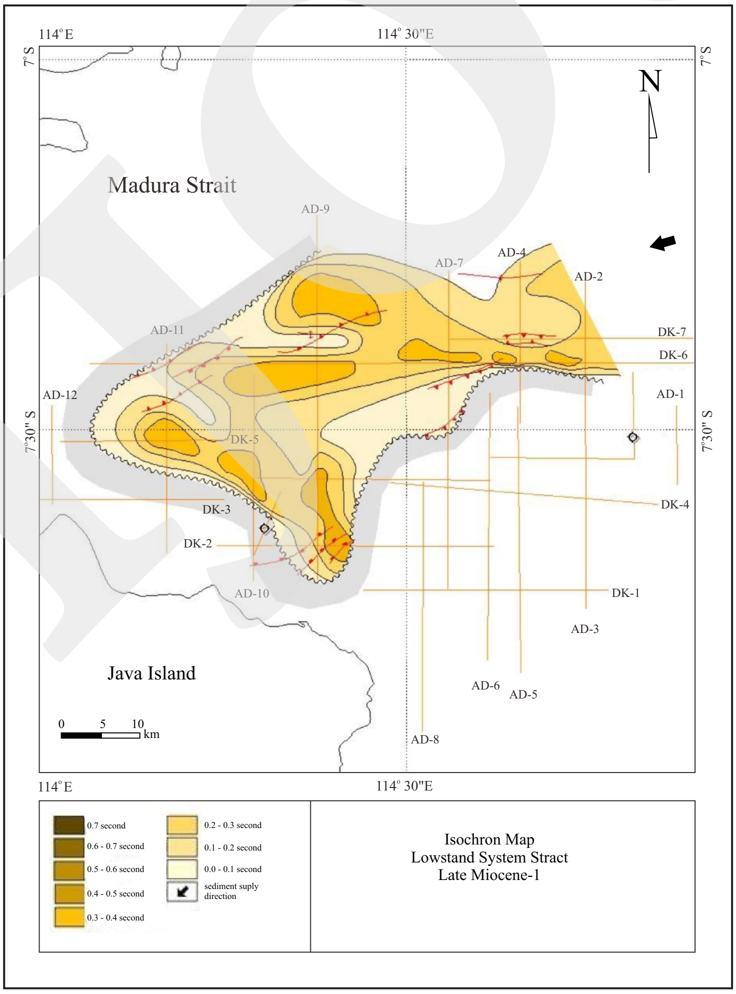

Figure 4. Isochron map of HST MM-1.

supply is generally thought to originate from the north-northeast (Martodjojo, 1978). It is inferred from the thickness of the sediments in HST MM-1, then were experiencing thinning to the west, east, and south-west.

Middle Miocene-2 Sequence (MM-2 Sequence)

The Middle Miocene-2 sequence (MM-2 sequence) comprises the Transgressive System Tract deposition in Middle Miocene-2 (TST MM-2) and the Highstand System Tracts deposition in Middle Miocene-2 (MM-2 HST). The distribution of TST MM-2 is slightly different from the distribution of TST MM-1, but in general it still shows thinning to the south, southwest, and the elevation of the surrounding areas. The deposition of TST MM-2 more developed in the middle part of the studied area. Formation of the TST MM-2 is affected by a quick relative sea level rise that produced onlap patterns in seismic similar to the Oligocene sediments (Figure 3). Sediment dispersal patterns are estimated to show sediment sources for TST MM-2 originated from the north-northeast.

The accumulation of the Highstand System Tract deposits in Middle Miocene-2 (HST MM-2) is thicker in the western part of the studied area. In general, the HST MM-2 had been thinning in the range 0.0-0.3 seconds TWT on parts of the boundary deposition, especially on the west, east, and south. While the range of 0.3-0.6 seconds TWT thickening occured in the central part of the Highstand System Tract and the Middle Mio-

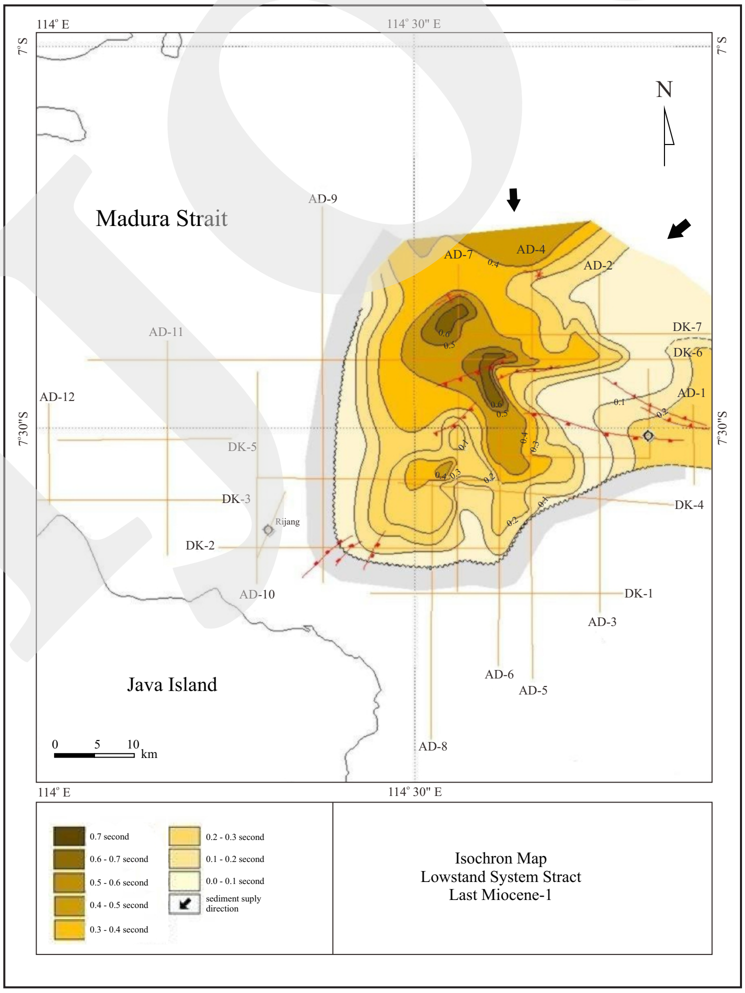

Figure 5. Isochron map of HST MM-2.

cene-2 (HST MM-2). This is caused by a high sediment supply that did not match the existing accommodation capacity. As the consequence, the deposition moved towards the lower basin located in the eastern part of the studied area (Figure 5).

Late Miocene-1 Sequence (LM-1)

Late Miocene-1 sequence (LM-1 sequence) was controlled by the Lowstand System Tract deposition in the Late Miocene-1 (LST LM-1) and the Transgressive System Tract deposition in Late Miocene-1 (TST LM-1). The Highstand System Tract deposition in Late Miocene-1 (HST LM-1) is estimated to develop at the next level above the Late Miocene structure. Since this study was limited only from the Middle Miocene to Late Miocene sediments, then further detailed analysis was not done beyond the upper peak of the Late Miocene sequence.

The Lowstand System Tract deposition in Late Miocene-1 (LST LM-1) is the first system tract deposited on the top of the Middle Miocene sediments. As for the Lowstand System Tract deposition in Middle Miocene-1 (LST MM-1), this system tract was deposited when relative sea level fell faster than the decline in the basin subsidence on the basis of a relatively shallow surrounding areas (the areas of shelfs). The rapid drop in the sea level generated the downlap patterns (Figure 6). The distribution of the Lowstand System Tract deposition in Late Miocene-1 (LST LM-1) was very broad, almost filling the entire peak of Middle Miocene sediments. These sediments were limited by elevations located in the southern and northern parts of the studied area.

Sediments thin towards the south and west ranges between 0.0 - 0.2 seconds TWT. This depletion occurred due to deposition of Lowstand System Tract in Late Miocene-1 (LST LM-1), onlap to the Early Miocene sediments that resulted from a tectonic rise of the southern studied area (Figure 6). This system tract also thickened in the middle to the west of the studied area where lower areas range from 0.2 - 0.4 seconds TWT (Figure 7). The distribution of the Transgressive System Tract deposit in Late Miocene-1 (TST LM-1) is different to the distribution of the Transgressive System Tract deposit in Middle Miocene-2 (TST MM-2), but in general it still shows thinning to the south. The deposition of the TST LM-2 more developed in almost all parts of the studied area. The formation of the TST MM-2 is affected by a rapid relative sea level rise which produces onlap patterns in seismic recordings.

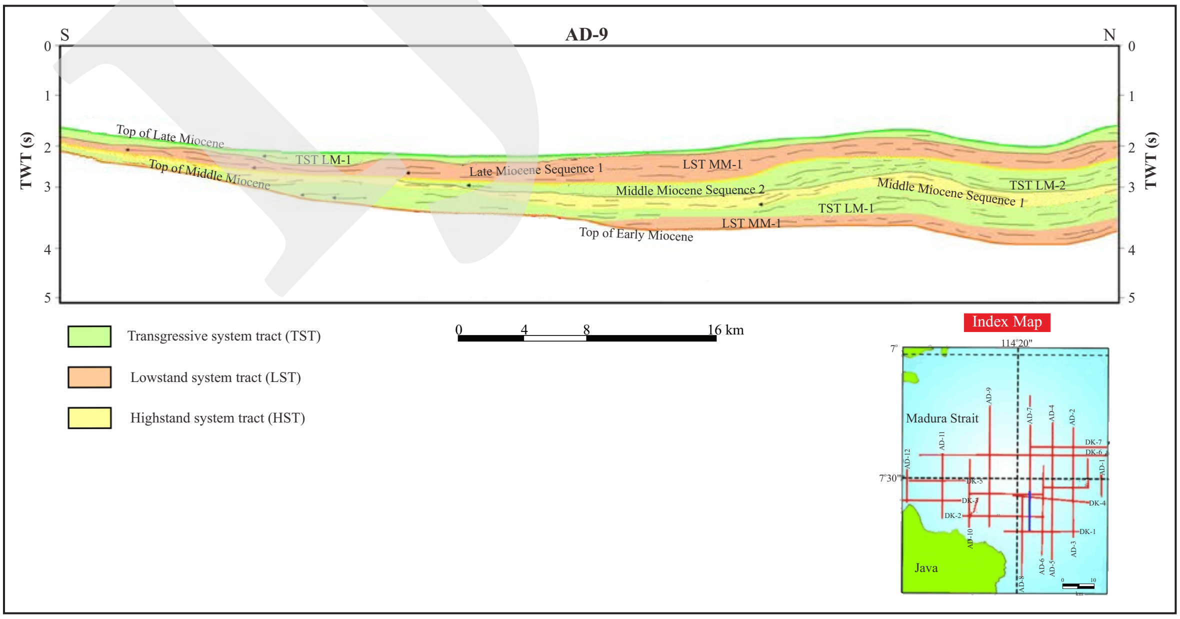

Figure 6. Interpretation of seismic line AD-9.

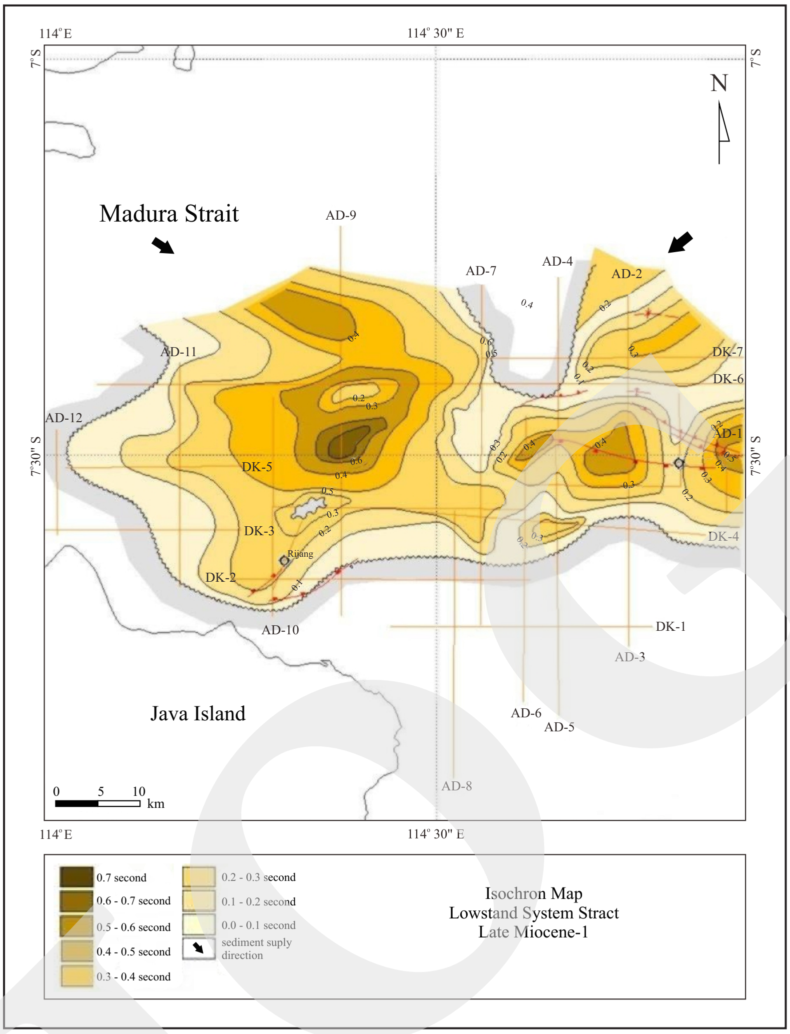

Figure 7. Isochron map of LST LM-1.

Conclusions

The sedimentation order in Middle Miocene to Late Miocene can be divided into three depositional sequences:

- Middle Miocene sequence-1 (MM-1 sequence) consisting of the Lowstand Tract System deposit in Middle Miocene-1 (LST MM-1), Transgressive System Tract deposit in Middle Miocene-1 (TST MM-1), and Highstand System Tract deposit in Middle Miocene-1 (HST MT-2).
- Middle Miocene sequence-2 (MT-2 sequence), composed of the Transgressive System Tract Middle Miocene-1 (TST MM-2), and Highstand System Tract deposit in Middle Miocene-1 (HST MM-2)
- Late Miocene sequence-1 (LM-1 sequence), comprising Lowstand Tract System deposition in Late Miocene-1 (LST LM-1) and Transgressive System Tract deposit in Late Miocene-1 (TST LM-1).
- The analysis results of sequence stratigraphy tend to indicate that hydrocarbon potential in the studied area is classified into two groups, based on the type of trap, namely: Anticline trap; the deposition LST MT-1, MT HST-1, and the HST MT-2 and the HST MT-2 stratigraphic traps; the deposition LST MT-1 forms a pinchout feature at altitude in the north, HST MT-1 forms pinchout at altitude in the south and in the north, HST MT-2 forms pinchout at altitude in the south, and LST MA-1 with pinchout at altitude in the south.

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References

Bemmelen, R.W.Van, 1949. T*he Geology of Indonesia,* IA. Government printing office, The Hague Netherland, 732pp.

Kusumastuti, A., Darmoyo, A.B., Suwarlan, W., and Sosromihardjo, S.P.C., 1999. The Wunut Field: Pleistocene volcaniclastic gas sands in East Java. *Proceedings, Indonesian Petroleum Association, 27th Annual Convention and Exhibition,* Jakarta, p.196-197, 204-206.

Martodjojo, S., 1978. *Sedimentation Regime of East Java.* Geology Departement of Institut Tektnologi Bandung (ITB), Bandung.

Sangree, J.B., Mitchum, R.M., and Vail, P.R., 1993. *Application of Sequence Stratigraphy to Hydrocarbon Exploration.* AAPG Memoir, p.2-353.

Tucker, M.E., 1982. *The Field Description of Sedimentary Rocks*. John Wiley & Sons, New York, Toronto, 112pp.

Walker, R.G. and James, N.P., 1992. *Facies Models; Response to Sea Level Change.* Geological Association of Canada, 409pp. DOI:10.1002/gj.3350290317