CHAPTER II
REGIONAL GEOLOGY

The Madura Island is located in the northern of Surabaya (capital city of East Java province) at position of UTM 49M 680000 – 855000 and 9200000 - 9245000 or WGS84 7° 0′ 0″ S, 113° 20′ 0″ E -7, 113.333333. The Madura Island is included to the North East Java Basin spread from onshore of East Java Island to the offshore of Banda Arc. Tectonically, nowadays, North East Java Basin has been placed in back arc basin setting from the southern subduction of Australian plate trough the Eurasian plate.

II.1 Physiographic of East Java Basin

Physiographic of Java, including East Java, has been published by van Bemmelen in his book which title "The Geology of Indonesia". Generally van Bemmelen (1949) divided Java Island into 7 zones (Figure 1), there are:

1. Quartenary volcanoes
2. Alluvial plains of northern Java
3. Rembang-Madura anticlinorium
4. Bogor, North Serayu, and Kendeng anticlinorium
5. Domes and ridges in the central depression zone
6. Central depression zone of Java and Randublatung zone
7. Southern mountains

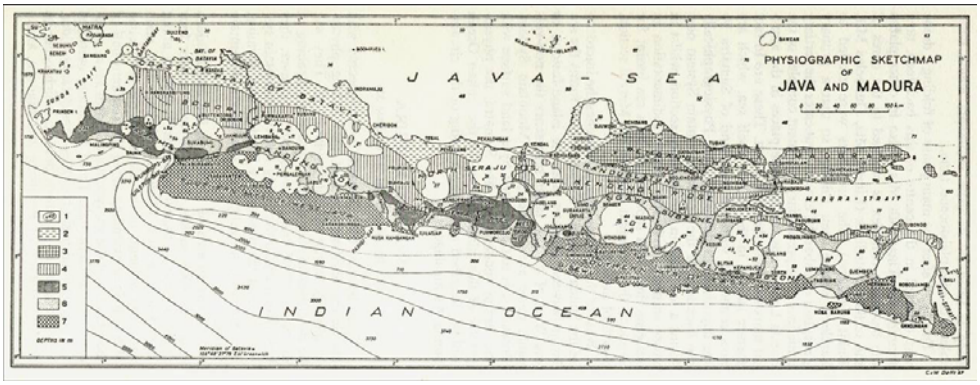

Figure 1. Physiographic of Java and Madura showing the continuation of anticlinoria from Madura to Rembang (van Bemmelen, 1949)

As the figure above, Madura Island is located in the Rembang-Madura anticlinoria. Structurally, that area is favorable for entrapping the hydrocarbon but in other hand, so many faults could be generated will disturb the accumulation of hydrocarbon. This anticlinoria is continued to the East of Madura until Kangean area.

II.2 Stratigraphy

Stratigraphy in East Java Basin including Madura Island has been studied widely. Since a lot of oil company operated in that area, they gave an own name for each formation they found. However, PSG (Centre of Geological Survey or Geological Research and Development Centre (GRDC before)) has published a general formation for all Indonesian area including Madura Island (Figure 2).

Geological map below shows the giant anticline along Madura Island with the east-west axis of the anticline. That anticline is exposing the Tuban Formation. Some formation is not exposed in Madura Island but exposed in other field of East Java Basin but the oldest formation (Ngimbang Formation) and the basement is not exposed anywhere in East Java Basin. Recognizing the Ngimbang Formation is only from well that has been drill in some location, otherwise, the basement of Madura Island is still on debate, weather it is mélange produced subduction of Indo-Australian plate or not.

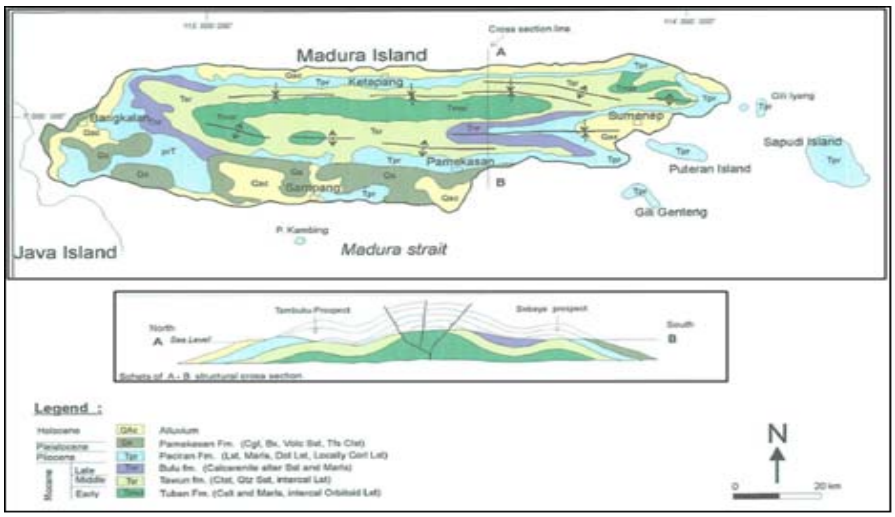

Figure 2. Geological map of Madura Island. (Gafoer and Ratman, 1999)

Complete stratigraphy column of East Java Basin has been published by Mudjiono and Pireno, 2001 (Figure 3). That column shows the relation between formations, lithology and also the tectonic episodes of each formation.

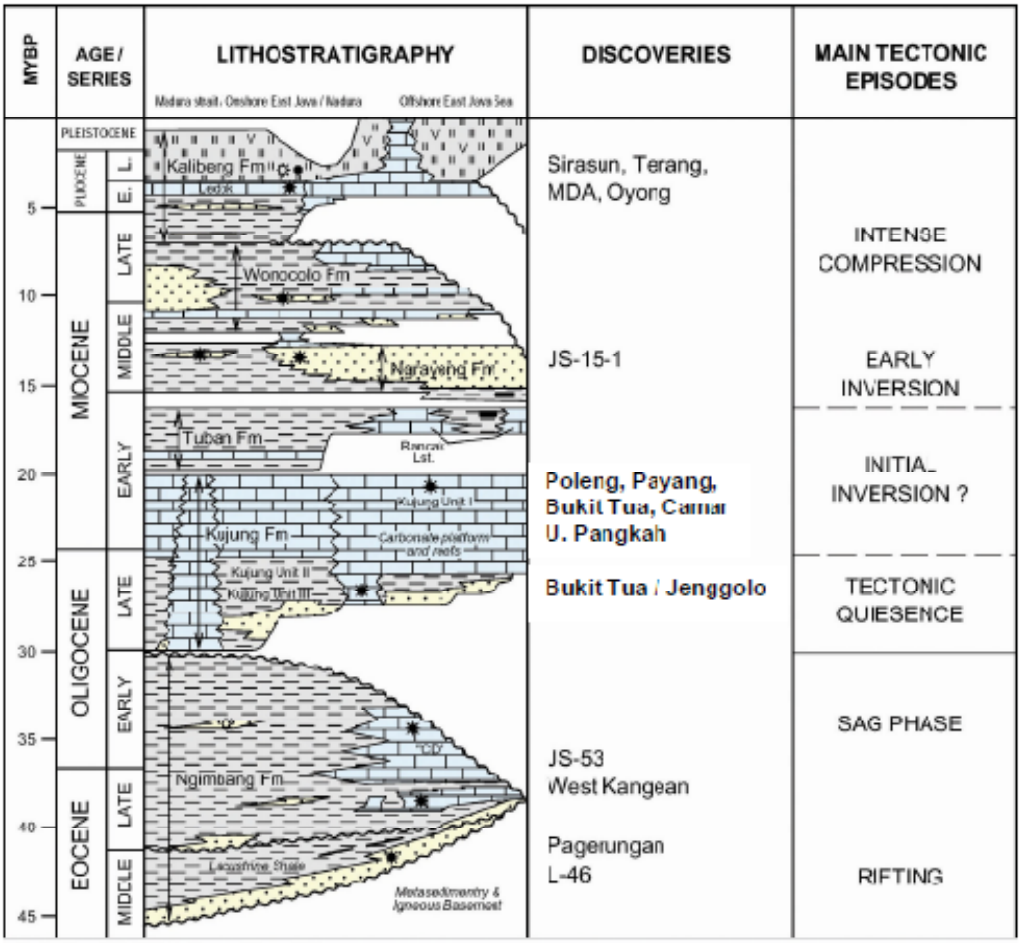

Figure 3. Stratigraphic composite of East Java Basin. (Mudjiono and Pireno, 2001)

Basement

The East Java Basin appears to be situated on intermediate crust of mélange group with a transition to oceanic crust, so than the basement of East Java basin believed consist of series mélanges of locally thrusted meta-sediments. Recent study shows there is possibility of the basements of East Java basin is not mélange deposit. This study introduced the concept of microplate of East Java. This microplate is come from an Australia continent and already has an East-West graben structure.

Ngimbang Formation

Coastal to deltaic clastic sediment has been deposited as a result of basement wash. This clastic sediment was followed by carbonate at the top of formation. Clastic sediment consists of sandstone interbedded with claystone and coal in several areas with varies of thickness. In several areas, carbonate was developed as decreasing of sediment supply, while the rest area was covered by marine shale as the top of formation.

In the eastern of East Java Basin, Kangean and Sepanjang areas, there are indications of pre-Ngimbang sediment overlie the basement. This sequence is consist of sandstone, siltstone and shales which unconformably overlies Cretaceous basements and unconformably overlain by the Ngimbang Formation. From biostratigraphy analysis, pre-Ngimbang was deposited at Paleocene to Early Eocene while Ngimbang Formation deposited at Middle to Late Eocene.

Kujung Formation

Kujung Formation was deposited at Early Oligocene to Lower Miocene mainly consists of marl and shale with subordinate amounts of sandstone and bank limestone. During the Kujung Formation deposition, a wide spread transgression covered western and central part of the East Java sea. This event implies a further advance of the sea to the Western and Northwestern part of the NE Java Basin.

Kujung Formation becomes a main target in exploring hydrocarbon in East Java Basin due to the distance to the main source rock is not too far and regional seal that place above the Kujung Formation. Kujung Formation divided into three units (Ardhana, 1993, *op.cit*. Mudjiono and Pireno, 2001) there are Kujung Unit I, II, and III while Pertamina-BPPKA (1996) reported Kujung Formation divided into three member; Poleng member at the lowest, Kujung shale, and Prupuh member. Prupuh member is mainly carbonate reef becomes main reservoir for East Java Basin while Poleng member or Kujung III contain of shale, siltstone, and limestone which trend to be sandy to the north in offshore area, while in Madura

Island, the sequence of Poleng comprise of fine grained, tuffaceous sandstone and limestone bank sequence (internal report PERTAMINA).

Tuban Formation

Tuban Formation was deposited in Early Miocene consists of renewed clastic sedimentation following the pervasive carbonates of the Kujung Fomration. Kujung Formation became the regional seal for petroleum system in East java Basin due to the thickness and lithology of this formation. A thick (1500 – 8000 ft) interval of carbonaceous shales with thin interbedded sandstones and marls become the rock filled the basin at that time. This cycle closed with reefal limestone accumulating on structural highs. Tuban Formation is the oldest formation that expose to the surface in Madura Island (Figure 2).

Ngrayong Formation

Ngrayong Formation which is consisting of quartz sandstone overlying the shales of Tuban Formation becomes another target in hydrocarbon exploration at East Java Basin. Ngrayong sandstone was deposited in marine environment during Middle Miocene and spread along Muriah Trough to the western edge of the offshore East Java Basin. This sandstone formation does not exist in Madura Island due to the palaeohigh of this area when the Ngrayong Formation is deposited but it is important target in surrounding area.

Middle Miocene to Plio-Pleistocene Deposit

Middle Miocene deposit is started with transgression event of East Java Basin deposited shallow marine clastic sediment. In early Middle Miocene to Late Miocene, in the onshore areas to the south, were deposited deep water marls and minor sand of Wonocolo Formation. Regression time is continued to Pliocene when inner neritic to deep marine sediment comprising mainly of sandy and glauconitic carbonates was deposited (Paciran and GL sediments). The GL and Paciran sediments consist of limestones, claystones, sandstones and siltstones. The volcanoclastic beds associated with the volcanic phase, which appear to be linked with the uplift of East Java, were deposited.

II.3 Tectonic and Structural Geology

The structural history of the East Java Basin cannot be separated from the structural history of the Java Island and its surrounding particularly and the tectonics of the SE Asia region. The tectonics of the SE Asia region are controlled by the interaction of 4 plates, the Indo-Australian plates to the south, Philippine and Pacific plates to the east, and the Eurasian plate to the northwest. There are two major trend of structure in the East Java Basin (EJB) controlled by those interaction; northeast-southwest trend and east-west trend (Figure 4).

Generation of northeast-southwest trend is believed as the continuation of spreading in Makassar Strait in the northern area. This spreading in Makassar Strait was produced horst and graben along that area. And this structural high and low become a boundary for fields in East Java Basin.

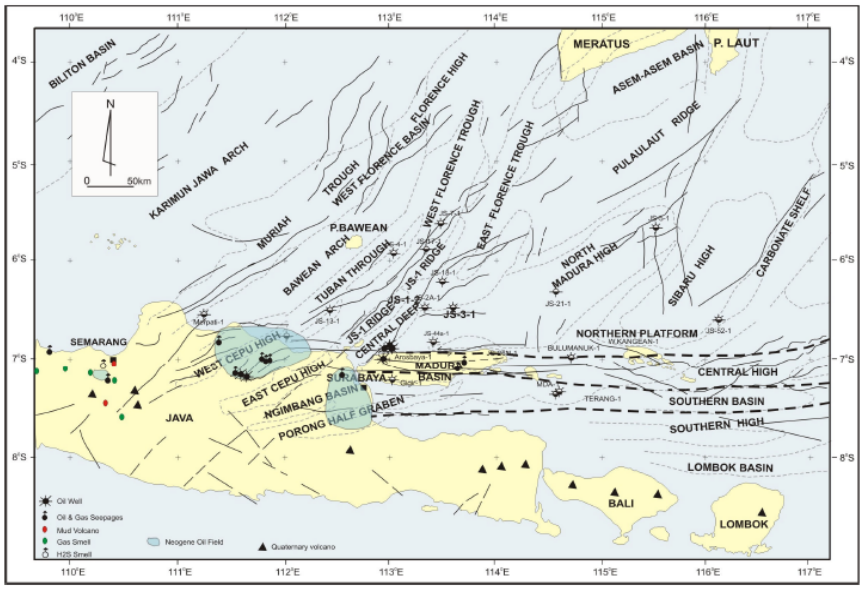

Figure 4. Tectonic elements of East Java Basin. (Sribudiyani *et al*, 2003)

The east-west direction will be the focus of the study and it is still in debate whether it is only formed by wrenching tectonic (Petamina BPPKA, 1996; Mudjiono & Pireno, 2001) or it is reactivation of normal fault existed before

(Matthews and Brandsen, 1994; Sribudiyani, 2003). Reactivation fault is likely more reliable one due to discovery of pre-Ngimbang sequence at the Kangean Island and also has given show of hydrocarbon (Matthews and Brandsen, 1994). The pattern of this structure is better shown by Figure 5.

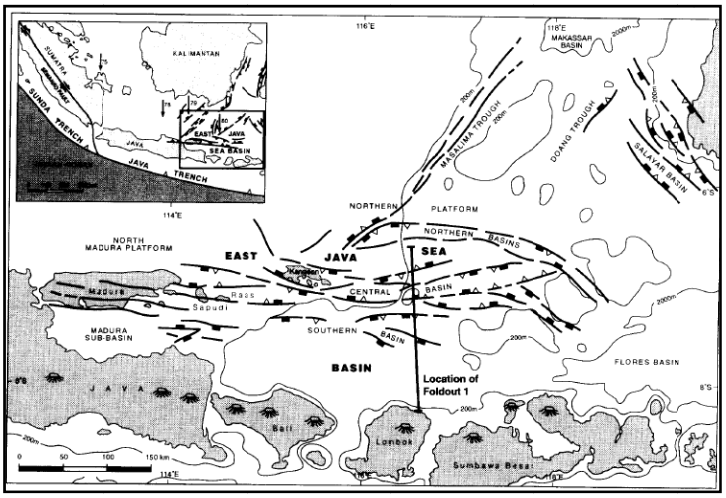

Figure 5. Structural pattern of Kangean Island that continue to Madura Island (Matthews and Brandsen, 1994)

The East-West continuation is not only shown by the tectonic regional of East Java Basin, but also from the Bouguer anomaly map (Figure 6). Even though it seems there is separation between Madura Island and Kangean Island, but the gravity pattern of both islands is similar. High anomaly is in the middle of island and very low anomaly at the southern.

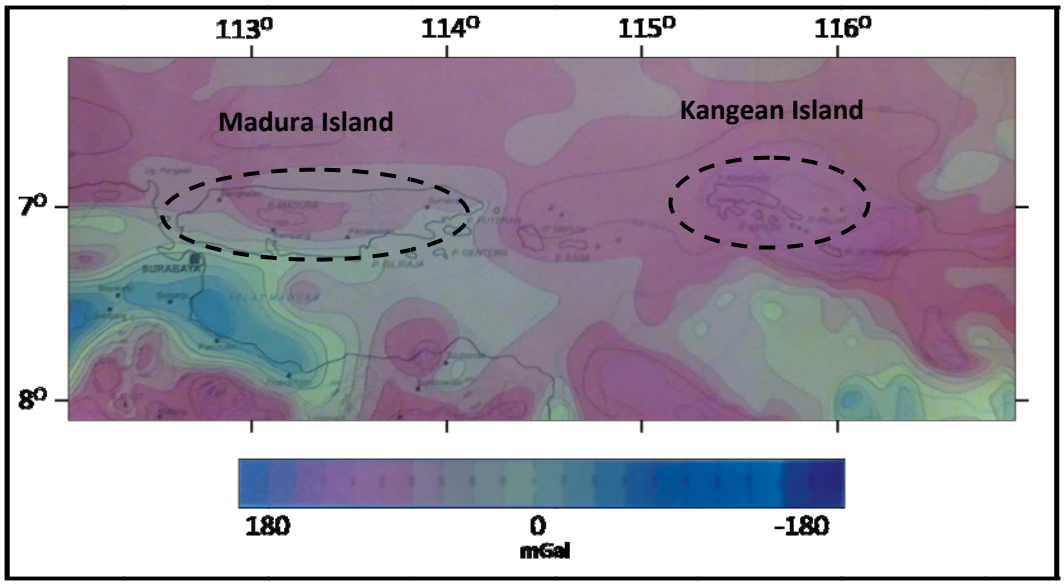

Figure 6. Bouguer anomaly map showing continuation from Madura to Kangean Island (Budiman *et al*, 1994).

The pattern of this anomaly is unique which it could be created by the structure controlled the form of Madura Island. This structure is similar with the pattern of the geological structure at surface. Giant anticlines were formed in Madura Island due to the wrenching tectonic of the island and make the bouguer anomaly in that area was high. Low anomaly at the south becomes the depocentre of the area where most of Ngimbang Formation was deposited and become giant source rock for that area. The hydrocarbon also could generate from that low anomaly and migrate to Madura Island.

Uplifting the Madura Island to the surface is cannot separated with the tectonic event of the area. Sribudiyani *et.al*, 2003 has divided the tectonic of East Java Basin into three phases called evolution of tectonics in East Java Basin. The evolution can be seen in the explanation below.

Late Cretaceous – Early Tertiary (70 – 35 Ma)

Java-Meratus subduction zone occur during this period as a result of movements of the Australian plate to the northeastward. This period is deposition time for Eocene quartz that distributed in all area in Java Island both offshore and onshore. In East Java Basin this Eocene quartz deposits is represented by Ngimbang Formation and found in two different graben systems. NE-SW graben called Meratus trend and also E-W trend called Sakala Fault system. In Kangean-Pagerungan area, even it can be found pre-Ngimbang Formation represented the most early synrift deposit in East Java Basin. This evidence was suggested the Sakala graben system was probably the oldest structure in East Java Basin and already filled by deposit before Ngimbang Formation is deposited.

Oligocene – Early Miocene period (35 – 20 Ma)

Decreasing the movement of the plate was happening during this time (Hall, 2002). The northward Australian plate slowed from 18 cm/ year to only 3 cm. the consequences of this slowing is the increasing of the angle of the subduction. During this period, the whole southeast region of Sundaland is uplifted and in

several areas like South China Sea, the rifting is happening and became active sea-floor spreading. In East java Basin, this period is the time when almost all fault is change into strike slip fault. This condition would be changed the structure of the formation existed.

Middle Miocene – Late Miocene period (20 – 5 Ma)

A sifting of subduction of the Australian plate is happen and a lot of tectonic region in East Java basin is changed. In the northern part, back arc basins were developed and sub-divided into several sub-basins were separated by basement highs. In the eastern of East Java which structurally dominated by E-W basement grain, including Madura Island, the compression tectonicsm due to the northward subduction has changed these E-W basement faults into a strike-slip movement (Manur and Barraclough, 1994). This strike-slip configuration is become important in constructing the entrapment in RMK (Rembang-Madura-Kangean) structure.

II.4 Petroleum System of East Java Basin

Petroleum system in East Java Basin has been proven completed from several discoveries. However, there are still many uncertainties concerning the generation of hydrocarbon until entrapment itself. Aspects of petroleum system in East Java Basin including Madura Island are describing in the following;

Source Rock

Satyana and Purwaningsih, 2003 has described geochemical analysis of hydrocarbon in East Java Basin (EJB). The research was concluded based on geochemistry analysis. The oils in EJB were derived from sub-oxic to oxic terrestrial to marginal marine source facies. Possible sources for the oils are non-marine to marginal marine of shales and coals of the middle-late Eocene Ngimbang/pre-Kujung, late Oligocene Lower Kujung, and the early Miocene Tuban Formation. Ngimbang shales and coals it seem become the source rocks for oils in offshore are while Lower Kujung and Lower Tuban shales and coals are the source rocks for the onshore area. In Madura Island, Ngimbang Formation

becomes the only source rocks because there are lacks of oil to source correlation for two other sources (internal report PERTAMINA).

Instead of grouping in environment classes, natural gases were grouped based on the process and resulted three types of natural gases that exist in EJB, they are; thermogenic, biogenic, and mixed thermo-biogenic gases but still the source rocks for these natural gases is the same with the source rocks for oil there are Ngimbang shale, Kujung shale and Tuban shale.

Reservoir Rock

Dominantly by carbonate rocks with some clastic rocks, reservoir in EJB exists from the Eocene formation until Pliocene formation. Deltaic to coastal sandstone of Eocene Ngimbang Formation become the oldest reservoir in the EJB although there is discovery of pre-Ngimbang Paleocene reservoir in the Eastern of Madura Island.

Carbonate reservoir rocks represent by Ngimbang carbonate, Poleng member, Prupuh Member, and Tawun carbonate while clastic reservoir rocks represent by Ngimbang clastic, Ngrayong Formation, Paciran, etc.

Seal Rock

Almost each formation in EJB has an intra-seal and possibly become the good seal for each play. Ngimbang Formation has a Ngimbang shale which possible to be a seal for the reservoir in that formation. Kujung formation also has a Kujung seal acted as source rock and also seal rock. Tuban shale at Miocene time becomes a regional seal for the whole reservoir underneath that formation.

Generation and Migration Subsystem

The data from PERTAMINA showed the Ngimbang Formation enter the peak of oil generation at the end of Oligocene (Tmax = 450 C and VR = 0.75), the onset of oil generation itself happen before that time. Thermal maturities will increase through time depends on the subsidence of the basin. At 6.3 Ma, the Ngimbang source rock progressively reached the gas window. At this time, theoretically

some crude oils must be converted into lower molecule to form gas hydrocarbon. Today, the maturity indicators at the base of Ngimbang sediment are reached at a high level thermal maturity with VR indicative of >1.6 %Ro.

Primary migration from source rock to the carrier beds is always relating to the saturation of kerogen source rock that transform to the hydrocarbon and the first time that system have the highest hydrocarbon saturation in the source rock occurs at 20 Ma (PERTAMINA internal report). Due to the properties of source rocks have low permeability, primary migration or expulsion will first occur in the most permeable zone that is relating to the fault zone where commonly create the fracturing zone which will increase the permeability of the rock. Secondary migration in carrier beds/ reservoirs occurs after the first. Paleogeography during this migration is the key to find the accumulation of the hydrocarbon in target area. The filling of some Kujung reservoir has started at approximately ~ 8 Ma and the later is being the case for the lower strata reservoirs (Tuban-Tawun reservoir).

Entrapment Subsystem

The timing of trap development is very critical to the hydrocarbon accumulation. And also the tectonic happens after the first accumulation will influence the accumulation. The filling of main reservoir, Kujung Formation, is stated at 8 Ma, so if it relates to the tectonic activity before 8 Ma and after that time, it will possibly to predict the reservoir filled or dry. The last tectonic happen to this area at Plio-Pleistocene when the faults existed were wrenched become left-lateral strike-slip. This wrenching also develops the giant anticline in the middle of Madura Island and becomes the structural trap in this area. Another trap is stratigraphic trap which is still unclear due to the limit of data and probably have an economical accumulation.