Sedimentation in Syn-Rift Set of Australia Continent Series in east part of West-Timor, East Nusa Tenggara

A U Nurhidayati¹, B H Utomo²
¹Research Center for Geotechnology, Indonesian Institute of Sciences (LIPI), Jl Sangkuriang, Bandung, West Java, 40135, Indonesia
²Geosains Delta Andalan Consulting, Jl Grand Galaxy City Central Park No. 53, Bekasi, West Java, 17147, Indonesia

*Corresponding author: ayuutaminurhidayati@gmail.com

Abstract. West Timor is a collision product of Banda Island and Australia Continental. It is the youngest collision product on the earth. The measuring section in the study area was assigned to know the outcrop and lithology of the study area. Aside, the biostratigraphy examination including pollen and large foraminifera and gravity measurement were assigned in the study area to understand the sedimentation system in the study area. The objective of the study is to ascertain the tectonic events and the basin filling of the study area in the West Timor of the syn-rift system. Based on the research conducted, the result indicates that the tectonostartigraphy in West Timor consists of syn-rift, post-rift, and syn-orogeny. The basin was formed in the Late Permian and the sediments were deposited in the terrestrial (lacustrine) environment. The rifting in the West Timor basin occurred in Late Permian-Jura and the sediments were initially deposited in the terrestrial and deepening to the deep marine during Trias and Jura. The Post-rift of West Timor occurred in the Cretaceous-Miocene. In the post-rift event, deep marine sediment was deposited.

1. Introduction
The needs of oil and gas is always increasing from year to year, while the oil and gas reserve alone is decreasing. Therefore, the exploration should be assigned to find the new hydrocarbon reserve in the sediment basin either of mature or frontier basin, especially in the East part area of Indonesia. Timor Island is well-known as hydrocarbon producer since early 20’s century. It is represented by many productive oil fields since Portuguese colonialism era. Some of them are still active and mined traditionally by society. Previously, hydrocarbon exploration and production was only focus in the east part of Timor Island which currently become Timor Leste. It was known that there is only one well existed in the west part of Timor Island (Banli-1 well) among 27 wells have been assigned in the Timor Island / onshore (Charlton, 2002). Most of exploration was conducted in the east part of Timor Island since in the east part of Timor Island has more oil and gas seeps compare to the west part of Timor Island. In addition, the west part of Timor Island is dominated by mud volcano seeps that can trigger overpressure while conducting the drilling.

Timor Island has a very complex geologic condition. The history of Timor Island formation consists of some phase. Every phase was identified with sedimentology, stratigraphy, and geological structure products. The objective of the study is to know the tectonic event and the sediment filling in the basin of Timor Island by analyzing the surface and subsurface data.
The theory of Timor Island formation is debatable. By finding new data in outcrops and laboratory analysis from north to south of the area, it will provide some new insights about geological history of Timor Island. Further, this new theory will affect the exploration concept of the Timor Island. This new exploration concept is expected to give the new prospect or potency for oil and gas.

2. Data and Methods
Geological Mapping especially Measuring Section (MS) that transect from north to south of the study area was assigned in this study. The MS traverse crosses some village such as Lil’ana, Kapan, Soe, Niki-niki, and Banli. In addition, the Banli-1 well that assigned by Amoseas in 1991 (Charlton and Wall, 1994) is also crossed by the MS traverse.

Laboratory analysis conducted in this study is biostratigraphy analysis including pollen and large foraminifer to understand about the environment and time of sediment deposition. Aside, the geophysics measurement which is gravity measurement was also conducted in this study. The result of the gravity measurement that obtain rock density information in the study area will be compiled along with the result of the MS data to interpret the thickness of the sediment that crossed from north to south of the study area.

3. Regional Geology
Tectonic concept of the Timor Island has been proposed and explained by the previous researcher. Some of the tectonic models are over-thrust (Audley-Charles, 1986), rebound (Chamalun dan Grady, 1978), imbrication model (Hamilton, 1979), duplex (Harris, 1991 and Charlton, 1991), and the latest tectonic model is basement involved/inversion (Charlton, 2012).

Overthrust model was proposed based on the geological surface data, in which overthrust layer from allochtonous material was well exposed. All of the allochtonous material in the thrust layer in Timor Island is well exposed. Therefore, this theory is supported by those evidences (Audley - Charles, 1968; Audley - Charles & Carter, 1972; Carter et al., 1976; Barber et al., 1977). They suggest that allochtonous layer that came from Eurasia plate in the north part was pushed to the Australia’s crust during the collision process. The large scale of fold and erosion in the sediment from the edge of the Australia continent occurred prior to thrust layer formation was not affected by the fold.

Figure 1. Regional Tectonic of West Timor (Charlton, 1987).
In simply way, *overthrust* model is an alignment of rocks that similar to its type but different source, frequently has the same age (Bowin et al., 1980). These rocks had been spread widely when the deposition occurred, afterwards aligned by compression and *overthrusting* during collision (Barber et al., 1977). In the other hand, Grady dan Berry (1977) were doubt about the validity of *overthrust* model since there is less evidence for *basal thrust planes*. They suggest that it should be *thrust faults* that almost flat, but in fact it was faults with the sharp dip. Grady dan Berry, 1977 also stated that in some area, *allochthonous* and *autochthonous* material were in normal starigraphy, and assigned the similar deformation (Hamson, 2004).

*Thrust* layer covered the Australia’s basement which is allochthonous layer and para-autochthonous layer, and propagation of imbrication during the formation (Fitch & Hamilton, 1974; Hamilton, 1979; Charlton et al., 1991; Charlton, 2000). These rocks have had different source but uplifted together as serial of pieces and aligned in Timor formed a chaotic complex from rock imbrication and mélange. Chamalaun dan Grady, 1978 rebutted this model since based on the field observation there is no support to prove the imbrication event from every unit. Besides, there is a few of mixing material between *para-autochthonous* and *allochthonous* material as described in the imbrication model. *incoherent chaotic mélange* theory was oversimplified for a tectonic evolution model in west Timor (Chamalaun, 1977).

![Tectonic Model of Timor Island (modified from Read, et.al, 1996).](image)

Bowin et al., 1980 also rebutted imbrication model. They claimed that every Australia’s affinity rock in Timor has been existed outside Banda arc prior to collision. Nevertheless, they did not show how those rocks existed in that location currently. The way of continental block being apart from Australia continent and included to fore arc of south part of Banda Arc was not well described.

An affinity of Eurasia micro-continent is able to form some crust material in collision zone complex. (Carter et al., 1976; Karig et al., 1987; Whittam et al., 1996; Richardson & Blundell, 1996; Linthout et al., 1997; Hall, 2002). The idea of micro-continent located in the north part of Barat Laut shelf and included to collision complex in 8 Ma affected the re-metamorphic Aileu Formation in the
north shore of West Timor (Berry & Grady, 1981; Berry & McDougall, 1986). Nevertheless, paleomagnetic data dictated the reciprocal. It showed that Timor turned to be a part of Australia’s allochton material at least in Late Perm and Trias. (Chamalaun, 1977).

Autochthon model or Rebound model rebutted both model, overthrust and imbrication model. In autochthon model, the formation of sediment assessment almost all of them came from sequence of uplifted Australia continental plate (Grady, 1975; Grady & Berry, 1977; Chamalaun & Grady, 1978). Material shifting passed the plate boundary toward mass transportation of olistos from generated ine unit known as Bobonaro Scaly Clay (Chamalaun & Grady, 1978; Harris et al., 1998.). Autochthon model delivered that overthrust and imbrication model lack of field evidence. The writer claimed that the debate can be solved if uplifted Basal layer can be found by detail research in Timor.

4. Regional Stratigraphy
Stratigraphic regional that developed in the West Timor Basin generally can be classified into three sequence unit such as Kekneno, Kolbano, and Viqueque sequences. Based on regional references about West Timor, Timor Island is a distal of Australia continental crust consist of sedimentary rocks deposited in marine environment.

West Timor Basin formation was started in Late Perm which is syn-rift phase. In this period of time, the extensional structural regime occurred. The break up in Australia continent and Gondwana occurred in the Late Jura that affected unconformity by emerging the deep marine volcanic. Cretaceous-Miocene is the post-rift phase. It identified by sedimentary rocks that deposited in the passive-margin environment. In this phase the tectonic activity is reduce compare to the previous phase.

Tectonic evolution in the Timor Island affected the stratigraphy succession from time to time changed rapidly. Deposition of syn-rift set started in the Late Perm-Jura that showed deepening upward succession. Syn-rift was started by deposition of lacustrine sediment in the Late Perm and deepening to deep marine environment (lower bathyal) in Jura.

5. Result
The result of the study was obtained from the Measuring Section including outcrop and lithology description, biostratigraphy as such pollen and large foraminifera analysis, and gravity measurement that crossed from north to south of the study area. Those approach subsequently generate the sedimentology system analysis in the Syn-Rift Set in the study area.

5.1. Detail of Syn-Rift Sedimentology
The oldest sedimentary rocks in the study area is Late Permian. Sawyer (1991) stated that the oldest sedimentary rocks in Timor Island is equivalent to Atahoc and Cribas formations. Both formation were deposited in deep marine environment. It suggests that the basin formation in Timor Island occurred in the marine environment.

In this study, the oldest rocks found is the sedimentary rocks deposited in the lacustrine. It indicates that the basin formation in Timor Island was formed in the terrestrial environment. Moreover, there is also found shallow marine sandstone (equivalent to Bisane formation) which deposited in transition-shallow marine environment.
Figure 3. Stratigraphy in the study area

Lacustrine sediment was found in the Ajaobali village, more specifically in Fatunausus ridge. Characteristic of this sedimentary rock is interlaminated of claystone and black shale, rich of organic content, some of them smelt burned-like, and non-carbonaceous. In the Ajaobaki village was found gas seep and was burned along the year. Palynology analysis dictates that it has fossil index such as *Plicatipollenites malabarensis* (Permian), *Plicatipollenis janakii* (Permian) *Protohaploxypinus samoilovichi* (Triassic), and *Falcisporites australis* (Triassic).
Figure 4. Reconstruction of stratigraphy cross section in Lilána-Soe-Niki niki-Banli Traverse

Transition-shallow marine sedimentary rock was found in Noil Bisane village which closes to Kekneno ridge. This facies is directly correlated with the younger facies which is deep marine facies that deposited in Trias. Characteristics in this facies is interlaminated of sandstone and claystone. The sandstone is grey, fine-medium sandstone, it has crossbedding and hummocky structure, and in some places it shows erosional contact, internal thickness of the sandstone is about 1-5 m. In some places was found *crinoid* and *ammonite*. Characteristics of claystone in this formation is light grey, carbonaceous, and internal thickness is 10-50 cm.
Carbonate platform was also found in the syn-rift phase in the Northern Mountain. Characteristics of the platform carbonate are reddish, some area rich of large foraminifera (*crinoid* dan *ammonite*). In some parts of northern mountain was found the contact of sedimentary rocks deposited in Jura (claystone). It indicates that the large fragments is on *broken formation*.

In figure 5, the gravity measurement was conducted in the study area with transect from north to south of the study area. There are several lines conducted. The gravity measurement generate the information about the rock density of the study area. Along with the measuring section data, it can interpret the thickness of sediment layer in the area in which the gravity was measured. Based on the gravity measurement conducted in the study area, the high rock density represent the more compact
and massive rock such as igneous, metamorphic, and carbonate rock. There are two areas have high rock density, north and south part of the study area. The high density in the north represent the serpentine and andesite, while in the south part it represents the carbonate rock.

5.2. Implication to Regional Tectonics

Significant discovery of sedimentary rock in this study can generate some differences compare to regional references in West Timor. It allows a new theory about tectonic evolution in the study area. In some regional references, the basin formation of Timor Island (Sawyer 1993, Charlton 2001, and Harris 2011) was started with deposition of deep marine sediment and interpreted as a part of distal of Australia continent.

![Figure 6. Paleogeography Model in the Late Permian](image)

Based on the stratigraphic chart in the regional references, the oldest rocks in the study area is shallow marine (equivalent to Maubisse Formation) and deep marine sediment (Equivalent to Atahoc and Cribas Formation). The new finding of lacustrine sediment in this study is contradictive to the regional references had established. Implication of this finding may affect the tectonic setting in the study area since the lacustrine sediment is deposited in the terrestrial environment.

![Figure 7. Paleogeography Model in Trias](image)
According to the pollen analysis from lacustrine sediment found, the basin formation was started in the Late Permian or older. Based on the valley and ridge configuration on gravity map indicates that there are three systems of half-graben pattern in the study area. Extensional mechanism is the basin formation mechanism in Permian-Jura. Sedimentary rocks that deposited in the same time with the basin formation change rapidly from time to time.

6. Conclusions
Basin formation in Timor Island took place in the terrestrial environment (lacustrine). Therefore, lacustrine sedimentary rock is the oldest rock in the early syn-rift. Syn-rift set in the Timor Basin consists of lacustrine facies, transition-shallow marine (shoreface) facies, and carbonate platform facies. Due to the evidence of lacustrine facies, the result of this study is contradictory to the prior established references. The new finding of this study affected to the tectonic regional setting that may imply the exploration of oil and gas of the study area. The potential petroleum system in the West Timor is as follow, potential source rock is lacustrine facies and potential reservoir is transition-shoreface facies.

References
[1] Audley-Charles, M.G., 1968. The Geology of Portuguese Timor. *Geological Society of London Memoir 4*.
[2] Barber, A.J., Audley-Charles, M.G., and Carter, D.J., 1977. Thrust tectonics on Timor, *Geological Society of Australia Journal* 24, 51-62.
[3] Berry, R.F., and McDougall, I.A., 1986. 40Ar/39Ar and K/Ar dating evidence from the Aileu Formation, East Timor, Indonesia, *Chemical Geology* 59, 43-58.
[4] Bird, P.R., and Cook, S.E., 1991. Permo-Triassic successions of the Kekneno area, West Timor; Implications for paleogeography and basin evolution, *Journal of Southeast Asian Earth Sciences* 5, 359-371.
[5] Bowin, C., Purdy GM., Johnston. C., Shor. G., Lawyer. L., Hartono. H.M.S., Jezek. P., 1980. Arc-continent collision in Banda Sea region. *Bull AAPG* 64:868-915.
[6] Brown, M., Earle. M.M. 1983. Cordierite-bearing schists and gneisses from Timor, Eastern Indonesia. P-T implications of metamorphism and tectonic implications. *J Metamorph Geol* 1:183-203.
[7] Carter.D.J., Audley-Charles.M.G., Barber.A.J. 1976. Stratigraphical analysis of island arc-continental margin collision in Eastern Indonesia. *Geol Soc London* 132:179-198.
[8] Chamalaun, F.H. and Grady, A.E., 1978. The Tectonic development of Timor. A new model and its implications for petroleum geology, *APEA Journal* 18, 102-108.
[9] Charlton, T.R., 1987. The tectonic evolution of the Kolbano-Timor trough accretionary complex, Timor, Indonesia, *Ph.D. thesis*, London University.
[10] Charlton, T.R., Barber, A.J., and Barkham, S.T., 1991. The structural evolution of the Timor collision complex, eastern Indonesia, Journal of structural geology 13, 489-500.
[11] Charlton, T.R. and Wall, D., 1994, New biostratigraphic results from the Kolbano area, southern West Timor; Implications for the Mesozoic-Tertiary stratigraphy of Timor, *Journal of Southeast Asian Earth Sciences* 9, 113-122.
[12] De Roever.W.P. 1940. Geological investigation in the South-western Moetis region (Netherland Timor), *Ph.D. thesis*, University of Amsterdam, 244 pp.
[13] Giani, L., 1971. The Geology of the Belu District of Indonesian Timor, *M.Phil. thesis*, London University.
[14] Grady, A.E., Berry, R.F. 1977. Some Paleozoic-Mesozoic stratigraphic-structural relationships in Timor Leste and their significance to the tectonics of Timor. *J Geol Soc Aust* 24: 203-214.
[15] Hall R. 2002. Cenozoic geological and plate tectonic evolution of SE Asia and the SW Pacific: computer-based reconstructions, model and animations. *J Asian Earth Sciences* 20:353-431.
[16] Hamilton, W., 1979. Tectonics of the Indonesian Region, U.S. Geological Survey Professional Paper 1078.
[17] Harris, R.A., 1991. Temporal distribution of strain in the active Banda Orogen: a reconciliation of rival hypotheses, Journal of Southeast Asian Earth Sciences 6, 373-386.
[18] Karig, D.E., Barber, A.J., Charlton, T.R., Klemper, S., and Hussong, D.M., 1987. Nature and distribution of deformation across the Banda Arc-Australian collision zone at Timor, Geological Society of America Bulletin 98, 18-32.
[19] Kenyon.C.S. 1974. Stratigraphy and sedimentology of the Late Miocene to Quaternary deposits in Timor. Ph.D. Dissertation, University of London.
[20] Milson.J., Sardjono.R., Susilo.A. 2001. Short-wavelength, high-amplitude gravity anomalies around the Banda Sea and the collapse of the Sulawesi orogeny. Techtonophysics 333:61-74
[21] Rosidi.H.M.O., Suwito Proyo.K., Tjokrosapoetro.S. 1979. Geological map Kupang-Atambua Quadrangle, Timor 1:250.000. Geological Research Centre, Bandung, Indonesia
[22] Sani, K., Jacobson, M.L., and Sigit, R., 1995. The thin-skinned thrust structures of Timor, Proceedings of the Indonesian Petroleum Association 24, 277-293
[23] Sawyer, R.K., Sani, K., and Brown, S., 1993. Stratigraphy and sedimentology of West Timor, Indonesia, Proceedings of the Indonesian Petroleum Accosiation 22, 1-20.
[24] Utomo, B.H. 2017. Tektonostratigrafi continental Australia pada Timor Barat bagian Timur, Nusa Tenggara Timur. Master Thesis. Institut Teknologi Bandung