Opening structure of the Bone Basin on South Sulawesi in relation to process of sedimentation

Struktur Bukaan di Cekungan Bone Sulawesi Selatan kaitannya dengan proses sedimentasi

Lili Sarmili

Marine Geological Institute of Indonesia (MGI)

Jl. Dr. Junjunan No. 236, Bandung 40174, Indonesia

(Received 07 July 2015; in revised form 23 November 2015; accepted 07 December 2015)

ABSTRACT: Sulawesi Island is situated on the three major plates, namely the Indo-Australian plate together with Continent Australia (Australian Craton) plate moves towards the North - Northeast and crust Pacific - Philippines moves towards the West - Northwest, causing the collision with the Eurasian plate (Sunda Land) which more passive or stable. The Bone basin is located between South Sulawesi and Southeast Sulawesi arms. This basin is formed by several fault system, such as, Walanae, Palukoro, West and East Bone faults and others. Several active faults are likely to be extended each other into the openings structure and characterized by the accumulation of young sediment in the Bone basin.

Keywords: Sulawesi, collision Bone basin, faults, sedimentation

ABSTRAK *Pulau Sulawesi merupakan tempat pertemuan antara tiga lempeng besar, yaitu lempeng Indo-Australia bersama-sama dengan lempeng Benua Australia (Australian Craton) bergerak ke arah Utara - Timurlaut dan Kerak Pasifik - Filipina bergerak ke arah Barat - Baratlaut sehingga terjadi tumbukan dengan lempeng Eurasia (Daratan Sunda) lebih bersifat pasif atau diam. Secara geologi Cekungan Bone terletak diantara Lengan Sulawesi Selatan dan Lengan Sulawesi Tenggara. Cekungan ini terbentuk oleh beberapa sistem sesar yaitu sesar Walanae, Palukoro, Timur dan Barat Bone dan lainnya. Beberapa sesar aktif tersebut kemungkinannya saling tarik menarik menjadi struktur bukaan dan ditandai dengan adanya akumulasi sedimentasi muda di cekungan Bone.*

Kata Kunci : *Sulawesi, tumbukan, Cekungan Bone, Sesar, Sedimentasi*

INTODUCTION

The study area is in the offshore of Bone basin in between the two provinces of South Sulawesi and Southeast Sulawesi. Physiographically, it is situated from the coordinates of 04° 00 ' S to - 06 ° 00' S, and from 120° 30' E- 121° 30' E (Figure 1).

The study area is located in the Bone Basin between the south and the southeast arm of Sulawesi. This basin bounded by the edges of the main fault trending north - south axis parallel to the axis of the basin which is support of the rate of sedimentation in the study area.

METHODS

Echosounder used is Sub-bottom Profiler and Bathy 2010 echosounder Reson 420. Measuring the depth of the sea in this investigation is to obtain the basic morphology of the seabed bathymetry map. Depth data taken simultaneously at the time of seismic reflection. With the acquisition of more depth data will facilitate the withdrawal of the sea depth contour.

Multichannel seismic equipment used in this study consists of major equipment such as 4 airgun with a volume of 150 cu in each airgun, fitted jackets and arranged side by side (parallel cluster). In the operational field activities airgun array was withdrawn 40 meters behind the ship, and the distance to the streamer behind airgun is 110 meters. During the survey two airgun operated by blasting 25 meter intervals, given the limited ability of seismic magnitude compressor about 190 SCFM in providing for the needs of high-pressure air to the airgun. Active streamer towed behind the ship at about 150 meters from the stern. Along streamer installed three Digibird Ion 5010 on the front end, middle and back streamer, which is used as a streamer depth control. During the survey Digibird position is monitored by the Positioning Control System (PCS) with software DigiCourse at the Geophysical Laboratory Geomarin III and sought to remain at a depth of 5-7 meters from the sea level. The position of depth streamer is depend on noise conditions, if it is too shallow or close to sea level noise

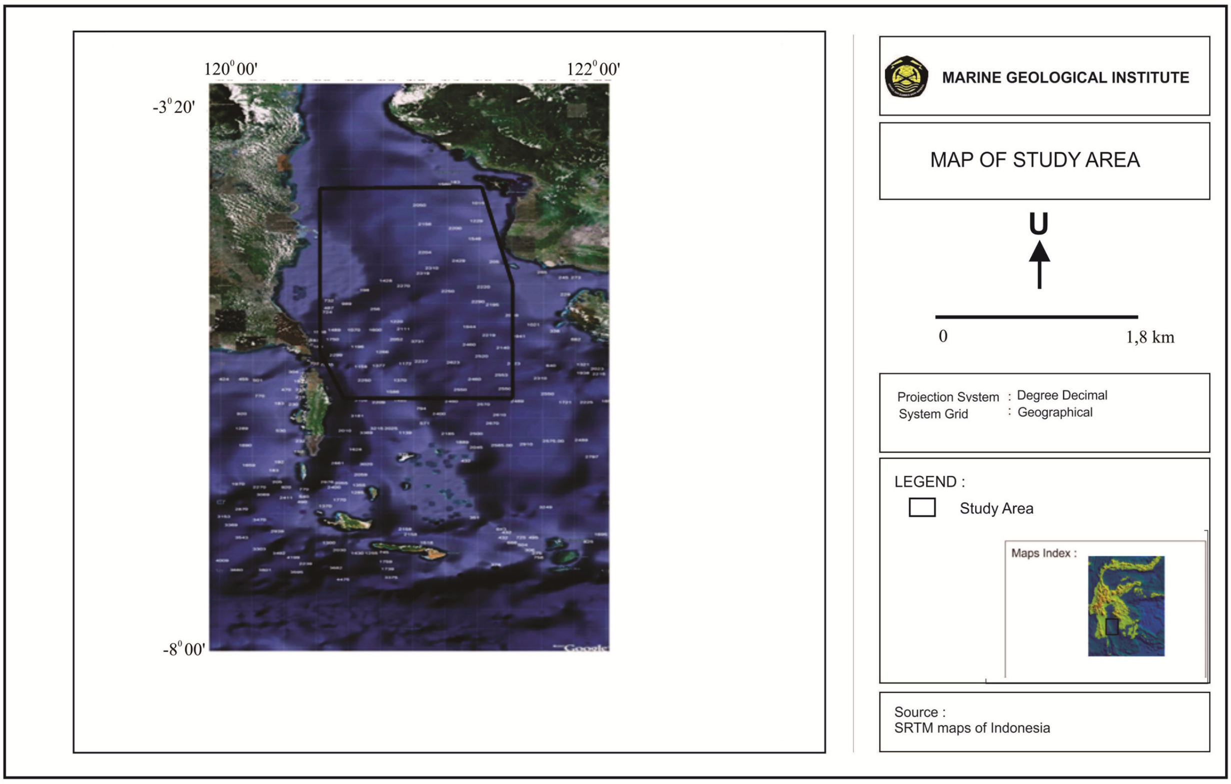

Figure 1. The study area of Bone Basin

wavelength would cover the signal reflected from the seabed.

Conversely, if too deep, the sensitivity of the streamer will be reduced due to high hydrostatic pressure, or is automatically turned off when the depth exceeds 30 meters.

INTRODUCTION

Sulawesi Island is situated on the three major plates, namely the Indo-Australian plate together with Continent Australia (Australian Craton) plate moves towards the North - Northeast and crust Pacific - Philippines moves towards the West - Northwest, causing the collision with the Eurasian plate (Sunda Land) which more passive or stable. These three plates commonly referred to as Triple Junction. This collision produce smal continent fragments (micro continent), a complex accretion prism, opening basins (extension), melange complex, island arc and collection of reverse faults and ophiolite rocks (Sukamto, 1975). In general, the island of Sulawesi, from west to east consisting of West Arm of Sulawesi which is represented by a series of volcanoes (volcanic arc), Central Arm of Sulawesi which is represented by rock alteration and Eastern Arm of Sulawesi which is represented by a complex of ophiolite rock and micro continents (Sukamto, 1975, Hamilton 1979, van Leeuwen, 1981, and Parkinson, 1991).

The Western Arm of Sulawesi is a volcanic arc consists of basement complex of middle Mesozoic in age, Cretaceous to middle Eocene limestones, and some Quaternary volcanic rocks. The composition of the volcanic rocks is generally calc-alkaline. On Neogen time (middle Miocene) volcanic activity spread across the West Arm of Sulawesi. The formation of sedimentary basins that have limited prospects only during the Pliocene, that is, syn-orogenic Molasse (syn-orogenic mollase) and Miocene depression zone of carbonate rocks (Barlian Yulihanto, 2004) mainly in the three mainland were constantly towards offshore. The region is a Sengkang sub basin on the east side of the West Arm of Sulawesi (near Bone Basin), also, Karama and Lariang basin. Sub Sengkang Basin is a part of the Bone Basin bounded by mountains Latimojong on its northern side, on the east by the Bone basin, to the west by the shoreline that extends parallel to the north-south of volcanic arc.

The eastern and southeast arms of Sulawesi mainly composed of metamorphic and ophiolite rocks. Tectonic contact known as a series of Batui thrust faults those are Australian – bird Head of Irian continental plates were slivering towards Sulawesi.

Couples of volcanic rocks and complex of ophiolite rocks as the evidence of the ubduction. The relationship of this model is that the presence of ophiolite rocks reinforces the oceanic crust and the upper part of the Australian - Irian mantle were split and eroded.

Bone Basin is one of basin type that can be known in South Sulawesi, namely: Forearc Bone Basin (or outer arc) and the around the southeast margin and the back arc basin. This basin is located between the volcanic arc and accreted non-volcanic arc. Bone basin with an elongated shape towards the south where the position is located between the southwest volcanic arc and southeast part of the fore arc or at the complex collision of Sulawesi. The Bone basin consists of three depocenter with a sediment thickness of more than 3 (three) seconds TWT below the seafloor surface. The basin sediment thickness can reach up to 5000 meters.

Bone Basin tectonically is a part of fore Arc Basin formed between the fore arc (Western Arm of Sulawesi) and non-volcanic arc (southeast Arm of Sulawesi). The Bone Basin is bounded by north - south trending faults which is almost parallel to the basin axis also support for sedimentation process.

The southwest side of the Bone Basin restricted by eastern of Walanae Fault and west Bone basin, where the northeast margin of the basin restricted by Eastern Bone Fault. Three main depocenter in this basin is depocenter with dipping to eastern known as Northern Bone Sub Basin that is located at north of the basin, also the two other depocenter are in southwest part of the basin.

This basin is formed by collision between microntinent of Buton with Sulawesi at the Middle Miocene. The basin is located in fore arc basin between volcanic arc on its west and non volcanic arc in its southeast.

Tectonic and Sedimentation

Pre-rift sequence of the Balangbaru Formation (Cretaceous)

The pre-rift sequence is composed of the Jurassic to Cretaceous Balangbaru Formation. This consists of flysch sediments deposited in bathyal to abyssal water, probably in a trench system. Cretaceous flysch is associated with ophiolites of oceanic crustal origins. It has been postulated that remnants of Cretaceous basins formed along the late Cretaceous plate margin (Bransden et al., 1992). It is thought that the Cretaceous section unconformably overlays a metamorphosed subduction complex and is itself uncomformably overlain by Eocene sediments (Coffield et al., 1993). Paleocene calc-alkaline volcanics of the Langi Formation occur to the west of the Walanae Depression. This is thought to be product of a subduction related volcanic arc (Yuwono et al., 1987).

Middle-Late Eocene Syn-rift Sequence of the Malawa / Toraja Formation

The Middle-Late Eocene sequence is represented by deltaic-shallow marine deposits of the Malawa/ Toraja Formation. Paleogeographic reconstruction of Middle-Late Eocene age reveals that this syn-rift sediment was deposited in non-marine/continental to marginal marine environments and gradually changes

eastward to an open marine environment. This facies distribution was strongly influenced by the N-S orientation of an extensional graben system. The formation of the associated extensional faults is interpreted to be part of the initiation of the Walanae and West Bone Fault system that occur along the western margin of the Bone Basin. In the Sengkang Sub-basin, Eocene sediments of the Malawa/ Toraja Formation comprise claystone, sandstones, conglomerates, coals, limestones and interbedded volcanics. The formation is generally made of non-marine deposits that change laterally towards the north of the Kalosi Block becoming dominated by red argillaceous sediments, being fluvial sediments in the lower part overlain by fluvio-deltaic to marine sediments and marine clastic and carbonate rocks. The thickness of these deposits varies between less than a hundred meters to over a thousand meters (Coffield et al., 1993).

Post Rift Sequence of the Oligo-Miocene Tonasa/Bone/ Makale Formation

The Oligo-Miocene Period was represented by a period of tectonic quiescence, followed by widespread carbonate deposition that covered most of the South Sulawesi Region and is equivalent to the Tonasa/Bone/ Makale Formation. In the western margin of the Bone Basin, in areas of the Sengkang Sub-basin, and in other onshore areas of the South Sulawesi region, Oligo Miocene sediments of the Tonasa Formation consist predominantly of limestones, sandstones, siltstones, and claystones. The Kampung Baru-1 well penetrated a 233 m sequence of limestones consisting of wackstones and bioclastic packstones. This was assigned to the Bone Formation, which is considered laterally equivalent to the upper part of the Tonasa Formation. The Bone Formation in Kampung Baru-1 ranges from Early Miocene to Middle Miocene (N6-N9) in age, which suggests marine deposition during the Oligocene in that area. Paleogeographic reconstruction of Oligo-Miocene time shows that the area of South Sulawesi was dominated by the development of carbonate platform facies, which changed eastward to carbonate slope and then to open marine/basinal facies. The

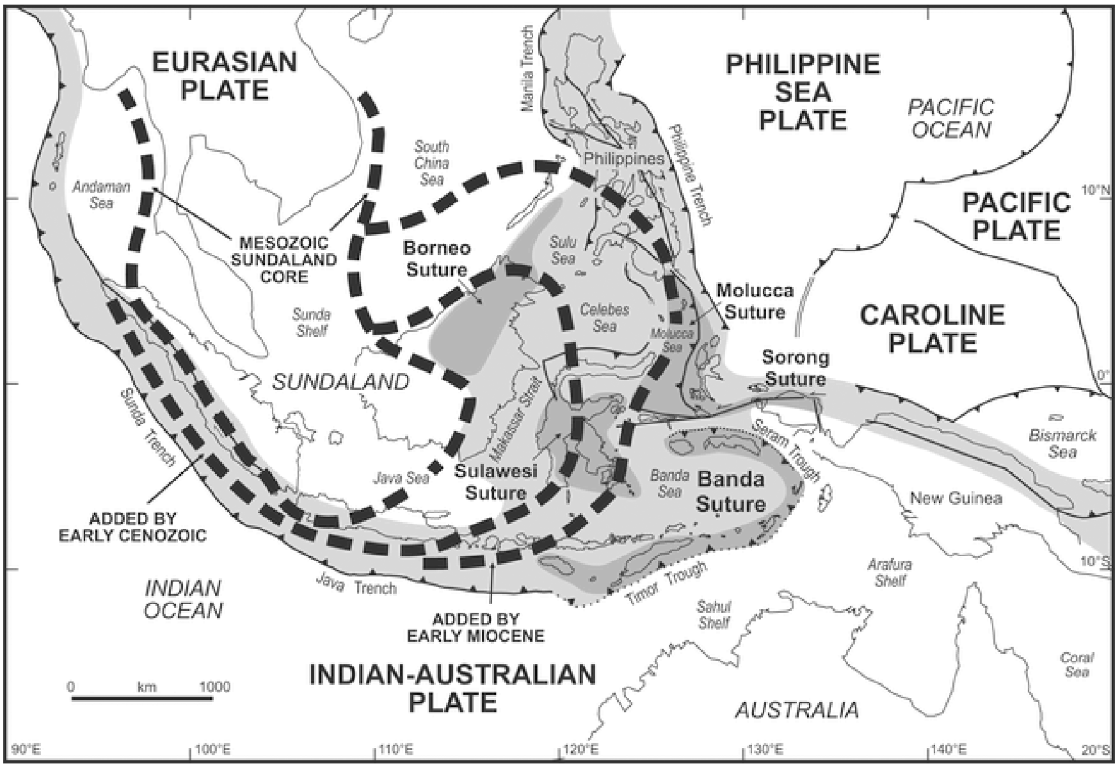

Figure 2. The plate boundaries of Indonesia (Hall and Smyth, 2008)

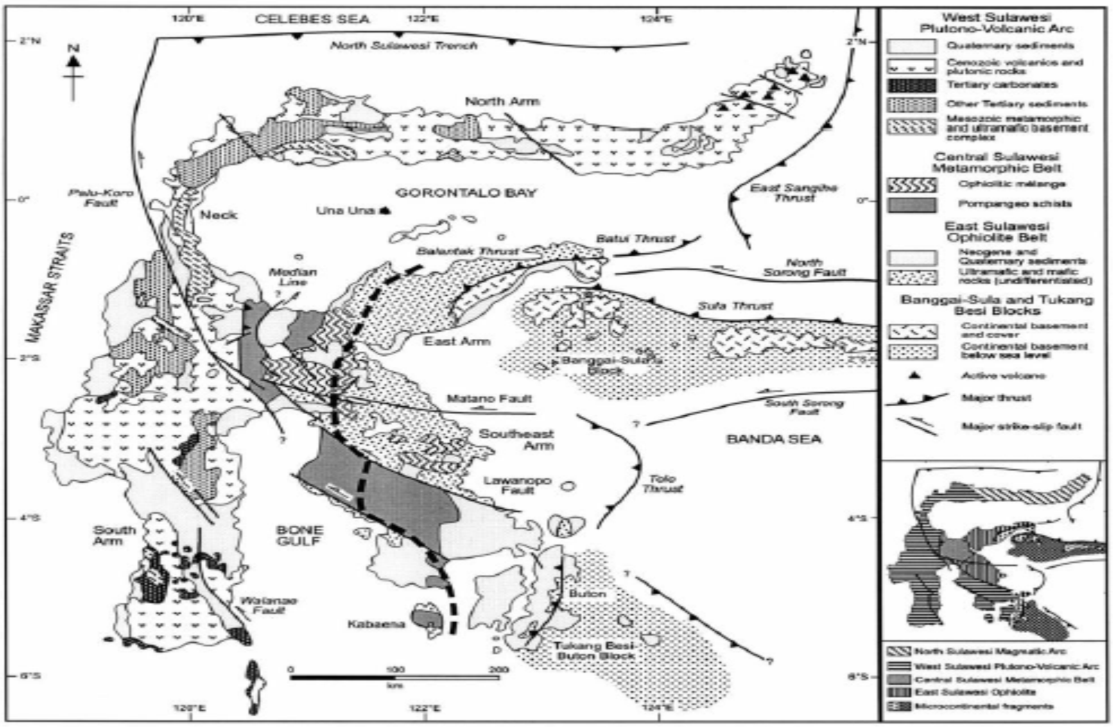

Figure 3. Geological Map of Sulawesi (Hall and Smyth, 2008)

platform carbonates consist predominantly of skeletal packstones andgrainstones, with skeletal grains consisting of larger foraminifera and smaller amounts of coralline algae, coral, bivalves, echinoderm plates, and subordinate volcanic grains. The basinal facies includes latest Oligocene to Early Miocene calciturbidites, olistostromes, and mass flow deposits, especially in the western basin slope and basinal area of the Bone Basin.

Middle-Miocene-Pliocene Collision Sequence

A Middle Miocene-Pliocene collision sequence was initiated by the deposition of an extensive clastic/ volcanoclastic section equivalent to the Camba Formation. Tectonically, the Middle Miocene time represents the period of collision of the East Sulawesi/ Banggai Sula microcontinent against the Early Tertiary accretionary complex in Eastern Sulawesi. This probably took place during the Middle Miocene, which resulted in left lateral motion along the Walanae and West Bone Fault Systems and is also associated with Middle Miocene volcanic activity. The Middle Miocene paleogeographic reconstruction indicates that the volcanic chain was stretched in a N-S direction parallel to the Walanae Fault System.

RESULT

Bathymetry

Sounding used with lines of seismic reflection which the over all total lines is more than 967.100 km. The all lines is divided into several lines, as shown in the figure 4.

Based on the bathymetric map, the basin is indicated by wide basin on its south and the north side it becomes narrow. This basin has a water depth about 700 - 3100 m below the sea level. The depth of the basin is also become shallower to the north. The south basin can reach about 3100 meters in depth. On the northern part of the there are severall small ridges, these phenomenas indicate the basin is still active in sedimentation. From the middle to the south of the Bone basin the basin is marked by west or east contour those are parallel with the axis of the basin. On its west side of the basin, the contour is relatively tighter than the east side of the basin. It means that the west side of the basin has a steep slope than the east side. The middle part of the basin generally formed a flat morphology while the west or the east side of the basin are marked by steep slopes. These steep slopes are indicated by a very tight contour of elevated hill.

Figure 4. Line of Bathymetry and Seismic Reflection in the research area

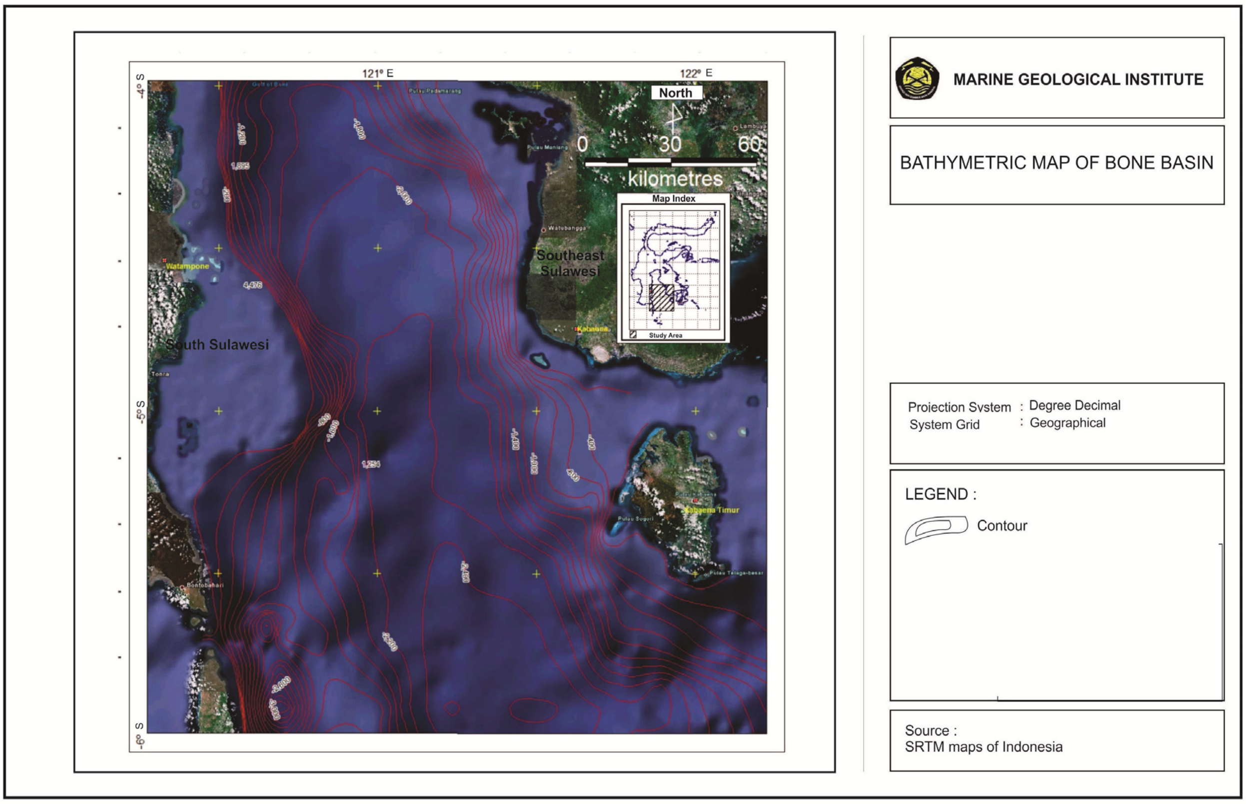

Figure 5. Bathymetry in the Bone Basin of South Sulawesi.

Seismic Reflection

Single or multi channel seismic reflection has undergone on the study area with a total overall line is more than 967.100 km. The seismic lines are mainly on east – west direction in order to cut perpendicularly to the axis of the Bone basin. The seismic lines are about 15 east-west lines with the longest line is 134.275 km, i.e, line 3 and the shortest line is line 17 which has a 34.525 km long. Only a few line of seismic mainly trending east - west are interpreted and considered to represent the research areas mainly related to the faults which are exist in this area.

Line 1

On seismic line 1 shown by the youngest sedimentary filling at western part of the basin as the result of active Wallanae fault. While on both side of the basin are indicated by elevated ridge of the basement. The middle part of the basin from west to east is covered by a very young sediment. The active fault is interpreted to motivate the process of sedimentation on the basin. The basin is limited by active faults on their east and west sides. It seems that the basin has an opening structure indicated by young sediment that has deposited from west to east.

If we look at the wide size of the basin, we conclude that the basin has undergone the opening or extention structures and end up by sedimentation.

Line 3

At the seismic line 3, the profiles showed of sedimentary filling both from west to east of the basin. In general, in the middle of the basin the sediment become thicker and to its west and east sides are become thinner. The basin is bordered by steeply faults and those are indicated by uplifted basement from both sides. The youngest sediment found on top the sediment layers seems to be deposited when the basin has encountered the opening structure.

Line 15

The seismic line of L 15, is almost on north tip of the study area. The basin becomes narrow and the seismic profile is different with the seismic profiles before. The profile shows that there are no elevated hills on both sides of the basin. The contour is shallower to the east to reach the west side of west margin of West Arm of Sulawesi. The youngest sediments filling the pockets (channel) having a chaotic pattern interpreted as a rough faction sediment coming from the mainland or the result of river erosion. The seismic profile does

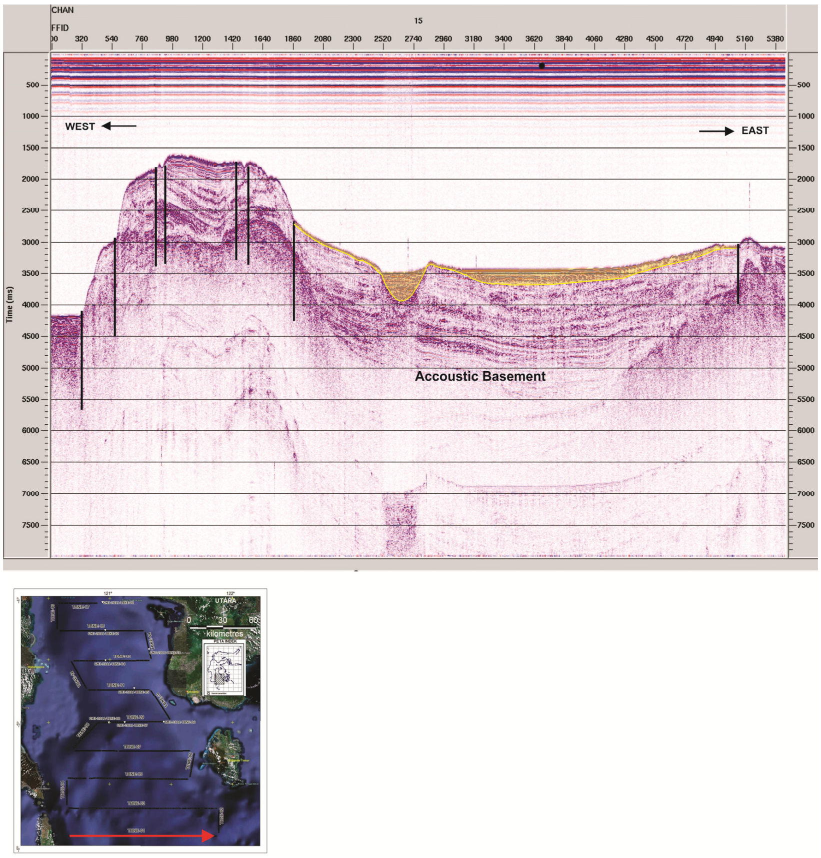

Figure 6. Seismic line 1 from west to east.

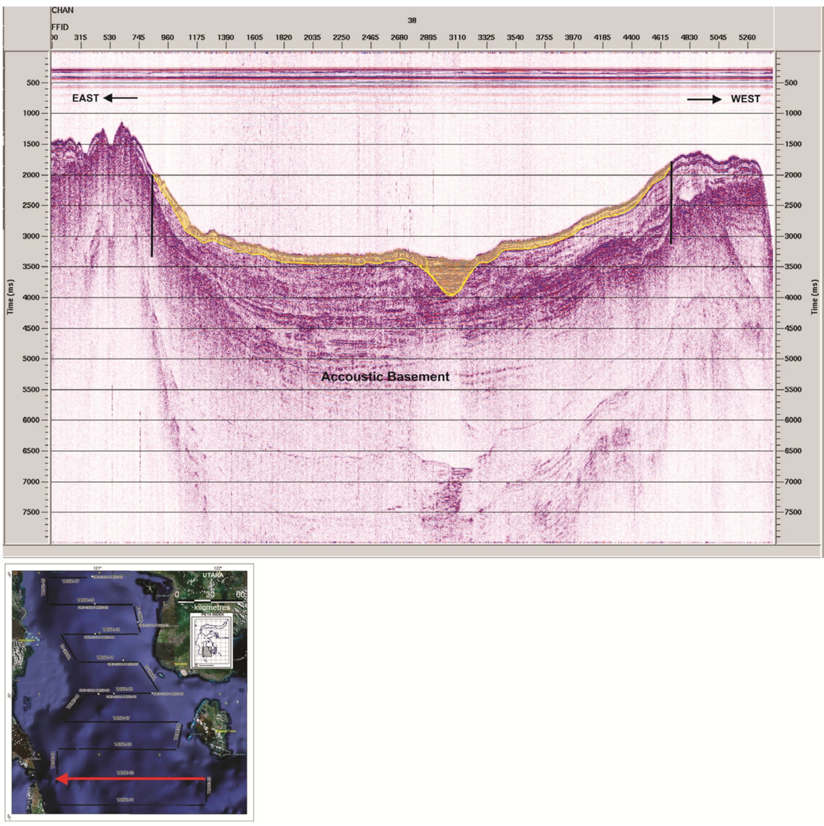

Figure 7. Sectional seismic reflection line 3 from east to west

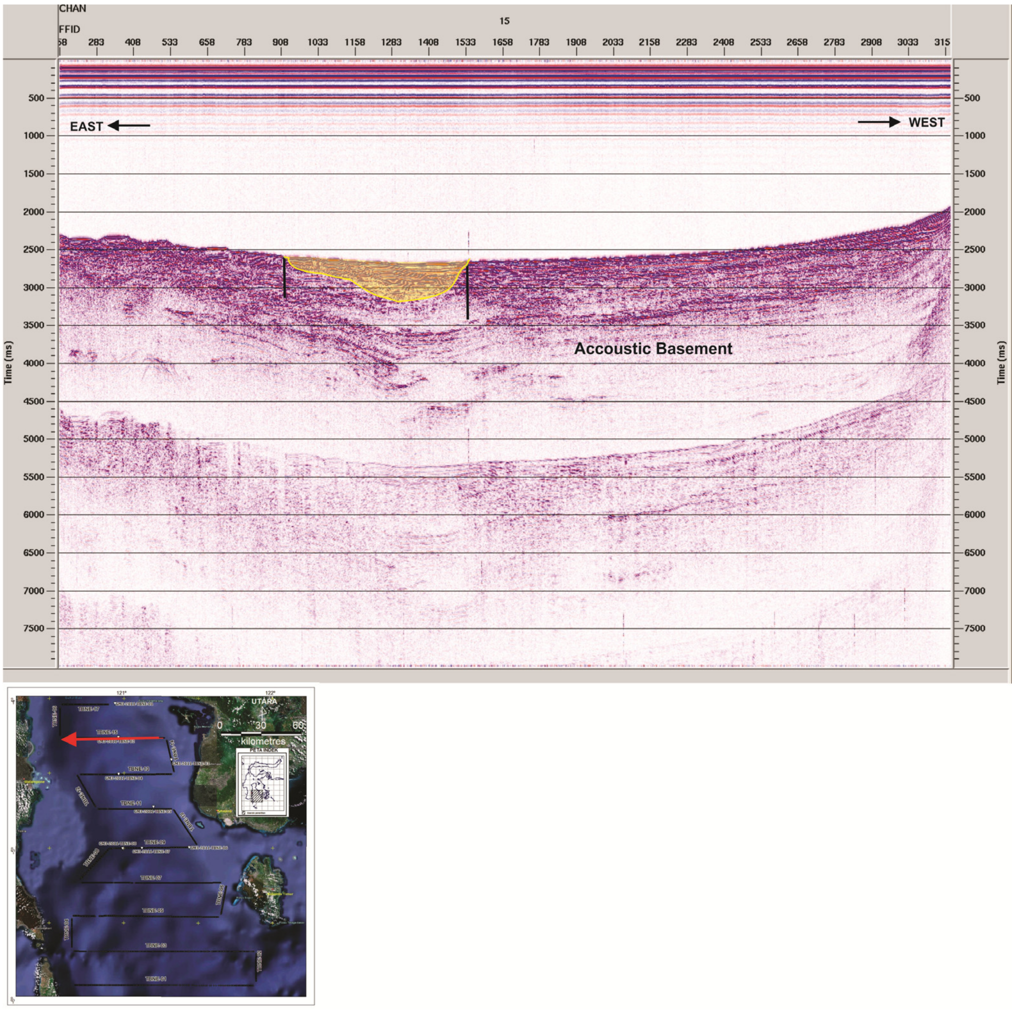

Figure 8. Seismic reflection profile of L 15 from east to west

not shows an opening structure but the channel is interpereted as a continuation of Palu-Koro sinistral Fault.

DISCUSSION

Tectonic of the Bone basin is based on interpretation of seismic reflection. The seismic profiles show the Bone basin is bordered on both sides by two uplifted basement high and in the middle by flat lying young sediment those are indicate there is an opening basin in this study area.

According to Satyana (2006), West Arm of Sulawesi originally as a part of Sundaland which is an island arc (magmatic arc). Then significant changes that change the direction of both magmatic arcs and subduction of Sulawesi from convex towards oceanic becomes somewhat straight. This conversion is due to changes in tectonic in surrounding areas such as the opening of the Makassar Strait, the opening of the Bone basin, opening Gorontalo Basin, and the Celebes Sea subduction. At 15-5 Ma there was a collision and docking of two microcontinent of Buton to southeast of Sulawesi and from the east (microcontinent Banggai-Sula). At this period the reversal direction is expected to occur either to magmatic arc and the subduction line from convex toward the ocean becomes concave toward the ocean (to the east). The action of arcs reversal on Sulawesi those occur through the displacement of the Earth's crust is called rotation.Southeast arm of Sulawesi rotates counter-clockwise so as to widen the study area is about on Bone Basin to the west, North Arm of Sulawesi rotates clockwise so close Gorontalo Basin. Then at 5 Ma up to the present reversal Sulawesi arc and tectonic escape occurred as a result of collision (Satyana, 2006).

The evidence of the opening on the study area can be seen on the seismic lines indicated by two big sinistral normal faults. On some seismic profiles indicate the direction of sedimentation more active came from the edge of West Arm of Sulawesi than from the edge Arm Southeast Sulawesi. On seismic line L 3, on the west and east side of the basin is thinner than in

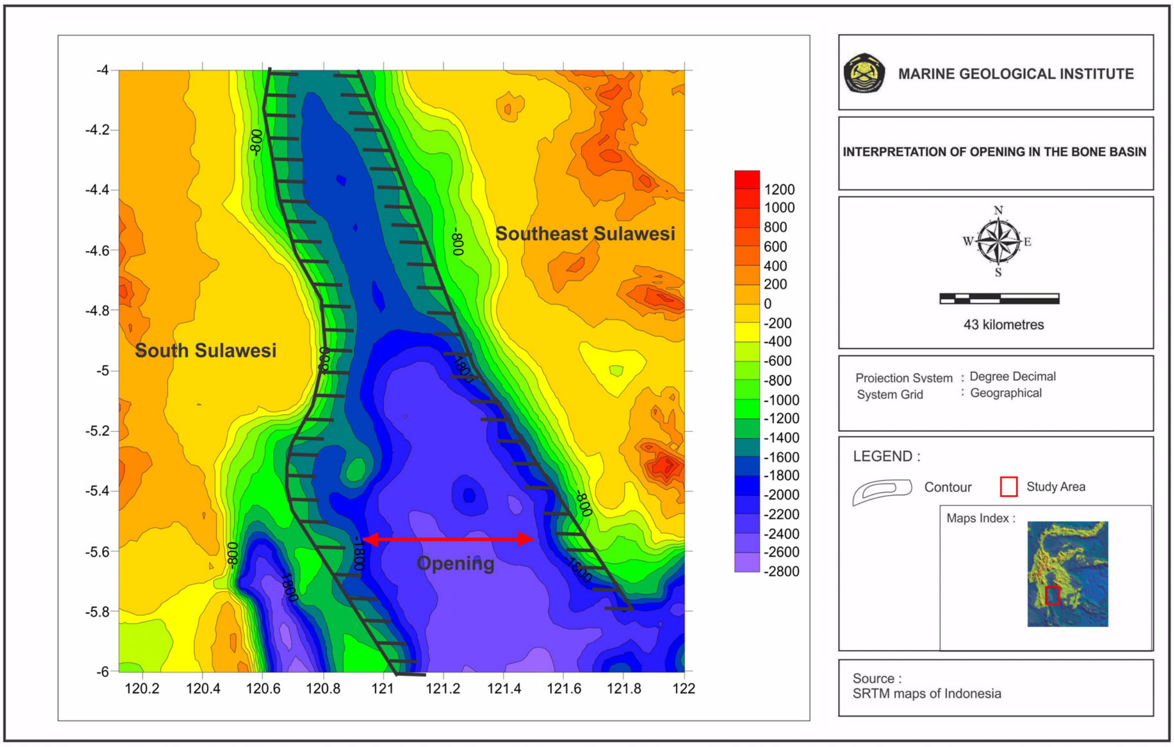

Figure 9. Interpretation of the opening in the Bone Basin

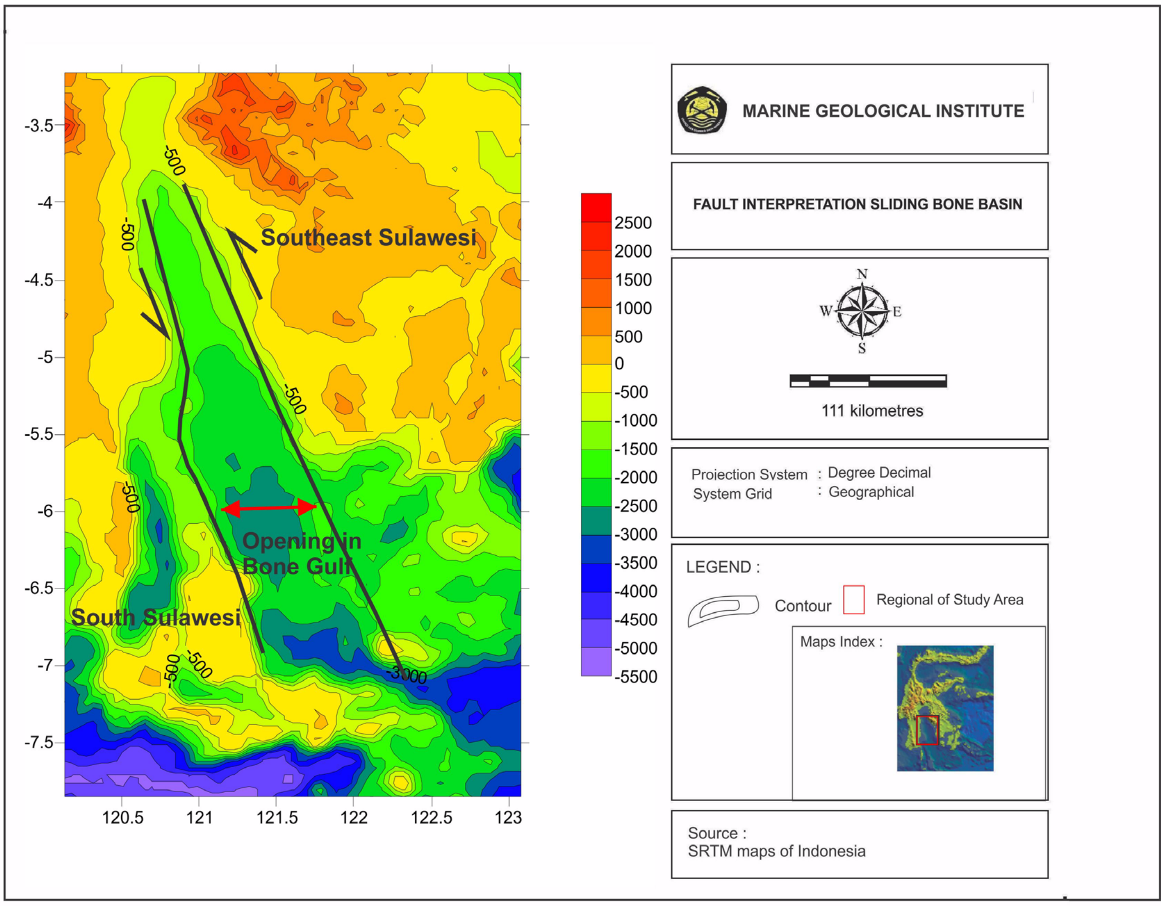

Figure 10. Fault Interpretation sliding Basin Bone

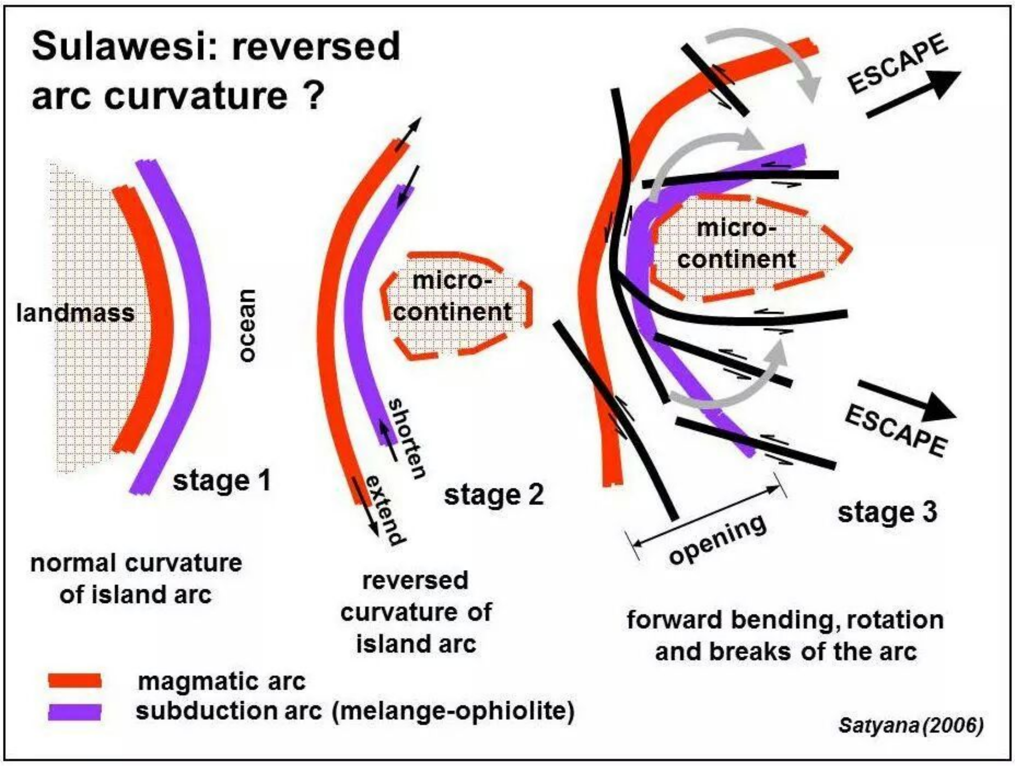

Figure 11. Formation Tectonics Sulawesi Island (Satyana, 2006)

the middle, it is interpreted that there was a process of extention from both sides. These extention is what has also become one of the opening occurs due to the evidence of reversal of the rotational arc - arc Sulawesi. Additionally, Line L 1 and L 3 are former Wallanae fault that formed from tectonic escape due to the collision process that continues until today.

CONCLUSION

The interpretation from seismic profiles shows the youngest sediment filling the Bone basin. The more open the Bone basin the more increasingly the widening sedimentary. The Bone basin also shows on seismic profiles that their edges flanked by two uplifted basement on its west and east. In addition, Wallanae Fault located in the west and part of Palu Koro Fault in the southeast of the study area plays an important role to process these openings which finally deposited the young sediments.

ACKNOWLEDGEMENTS

Thanks to the Head of Research and Development of Marine Geology Dr Ediar Usman for supporting to publish this paper. The author also would like to thank to all colleagues who have helped, discussion and corrected until the publication of this paper.

REFERENCES

[1] Bransden, P.J.E., and Matheus, S.J., 1992. Structural and stratigraphic evolution of the east Java sea, Indonesia: *Proceedings Indonesian Petroleum. Association, 21st. Annual Convention, v. 1, p. 417-453.*

[2] Coffield, D.Q., Bergman, S.C., Garrard, R.A., Guntino, N., Robinson, N.M., and Talbot, J., 1993. Tectonic and stratigraphic evolution of the Kalosi PSC area and associated development of a Tertiary Petroleum System, South Sulawesi, Indonesia: Proceedings Indonesian Petroleum. *Association 22nd. Annual Convention, v. 1, p. 679-706.*

[3] Hall, R. & Smyth, H.R., 2008, Cenozoic arc activity in Indonesia: identification of the key influences on the stratigraphic record in active volcanic arcs, in Draut, A.E., Clift, P.D., and Scholl, D.W., eds., Lessons from the Stratigraphic Record in Arc Collision Zones: *The Geological Society of America Special Paper* 436.

[4] Yulihanto, B., 2004. Hydrocarbon Play Analysis of Bone Basin, South Sulawesi. *IPA-AAPG Deepwater and Frontier Symposium Pages 333-348.*

[5] Hall, R. & Wilson, M. E. J., 2000, Neogene sutures in eastern Indonesia. *Journal of Asian Earth Sciences*, 18, 781–808.

[6] Hamilton, Warren, 1979. *Tectonics of the Indonesian Region*, United State Geological Survey, Prof Paper, 1078

[7] Parkinson, C.D., 1991. *The Petrology, Structure and Geologic History of the Metamorphic Rocks of central Sulawesi*: PhD Thesis, University of London, 378 p., unpublished

[8] Satyana, A.H., 2006, Docking and Post-Docking Tectonic Escapes of Eastern Sulawesi : Collisional Convergence and Their lmplications to Petroleum Habitat, Jakarta 2006 International Geosciences Conference and Exhibition, Jakarta, August 14-16, 2006.

[9] Sukamto, R., 1975. *The Structure of Sulawesi in the Light of Plate Tectonics* : Paper Presented at regional conferenceon the geology and mineral resources of SE Asia, Jakarta, August 4-7, p. 1-25

[10] Van Leeuwen, T,. 1981. *The Geology of Southwest Sulawesi with special to the Biru area.* In A.J. Barber & S. Wiryosayono (eds). The Geology and Tectonics of eastern Indonesia, GRDC Bandung, Spec. Publ. 2, p. 277-304.

[11] Yuwono, Y.S., Maury, R.C., Soeria Atmadja, P. and Bellon, H., 1997. Tertiary and Quaternary geodynamic evolution of South Sulawesi: Constraints from study of volcanic units. Geology Indonesia, v. 13, no. 1, p. 32-48.