GEOSEA '98 Proceedings, Geol. Soc. Malaysia Bull. 43, December 1999; pp. 103-111

Ninth Regional Congress on Geology, Mineral and Energy Resources of Southeast Asia — GEOSEA '98
17 – 19 August 1998 • Shangri-La Hotel, Kuala Lumpur, Malaysia

The effect of collision of the Banggai-Sula microcontinent to the tectonic development in Central Indonesian region

AGUS GUNTORO

Faculty of Mineral Technology
Geological Department
Trisakti University
Jl. Kyai Tapa 1 Grogol, Jakarta 11440, Indonesia

Abstract: The geology of Indonesia is well-known as one of the most complex in the world, especially in the boundary between Eastern and Western Indonesia which is called Central Indonesia where geologically it is situated in the triple junction of the three major plates; Indo-Australian, Eurasian and Pacific plates. Considerable hypothesis have been put forward to explain its tectonic history but it still becomes subject to controversy.

Makassar Strait, Sulawesi and Bone Bay are three major tectonic provinces situated in Central Indonesia which show very complex geology and tectonics. Several major faults existing in the region such as, Paternoster and Sangkulirang faults in Makassar Strait and Palu-Koro, Matano and Walanae faults in Sulawesi as well as normal faults in Bone Bay are believed to be related to one another in their formation and control the tectonic development of the region.

Geological and geophysical data in the region have been analysed to reveal the shallow and deep structure of the region. Seismic interpretation shows the presence of major faults indicating as extensional, compressional and inversion tectonics in Makassar Strait, Sulawesi and Bone Bay. While gravity models indicate the presence of oceanic crust in the middle of Makassar Strait and Bone Bay, as well as the presence of remnant subduction to the south of Bone Bay. The origin of oceanic crusts in Makassar Strait and Bone Bay are interpreted as due to the rifting process forming rift structure as half-graben. The driving mechanism of the rifting in Makassar Strait is suggested as a result of subduction roll-back of the Pacific Plate eastward since early Tertiary. Whereas the driving mechanism of the rifting in Bone Bay is due to the collision of Banggai-Sula Microcontinent to Sulawesi causing the displacement and rotation of two major faults, Walanae and Palu-Koro faults, and finally caused the opening of Bone Bay. However; the effect of the collision is not only causing the opening of Bone Bay but also effecting the tectonic development in Central Indonesia. This is interpreted on the basis of the orientation, pattern and timing of many major faults in Central Indonesia which is in agreement to the extrusion model of Tapponnier *et al.* (1982). The model has been used to explain the tectonic settings in Southeast Asia in relation to the indentation of India continent to Eurasia.

The result of this study also presents the tectonic model explaining the sequences of the tectonic evolution in Central Indonesia during the collision.

INTRODUCTION

Central Indonesian Region (CIR) is defined as an area situated in the boundary between Eastern and Western Indonesia, and consists of Makassar Strait, Sulawesi and Bone Bay provinces (Fig. 1). The CIR is bounded by two major subduction zones; in the west by pre-Tertiary subduction zone at the southeastern margin of the Sundaland built up by collages of Asian continental block, and to the east by the Early Tertiary subduction zone which is marked by the Selayar-Bonerate ridge. Whereas Banggai-Sula Microcontinent is a group of islands situated to the east of Central Indonesian Region (see Fig. 1), and it was part of microcontinent of Irian Jaya which had been detached during the Cretaceous time. The emplacement of the Banggai-Sula Microcontinent to the present position is interpreted to be responsible for the structural and tectonic development in the Central Indonesian Region.

How far the effect of the collision and what is the mechanism controlling the structural setting and tectonic development in CIR is still unclear, and it is the purpose of this paper to try to answer those questions.

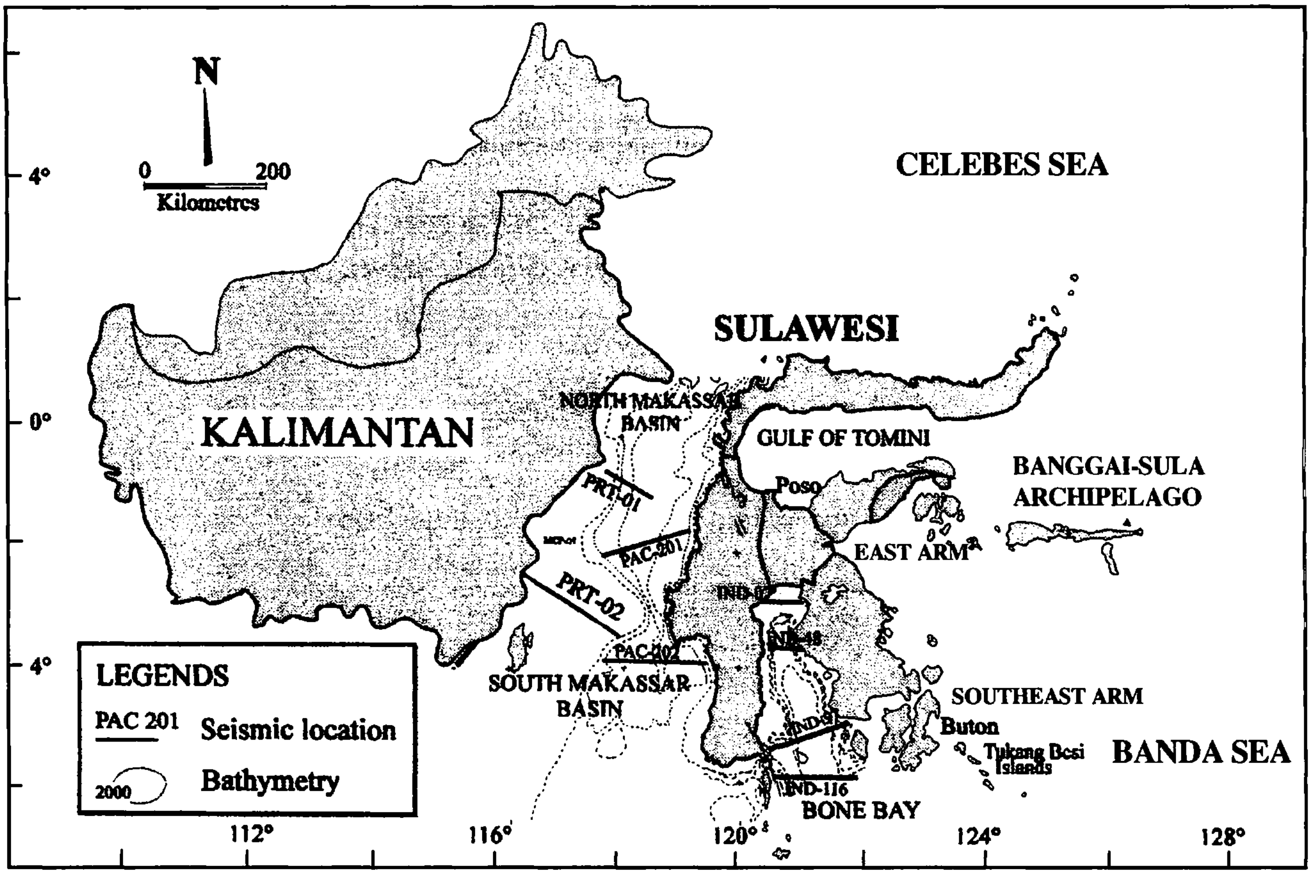

Figure 1. Location map, bathymetry and seismic location of Central Indonesian region consisting of Makassar Strait, Sulawesi and Bone Bay.

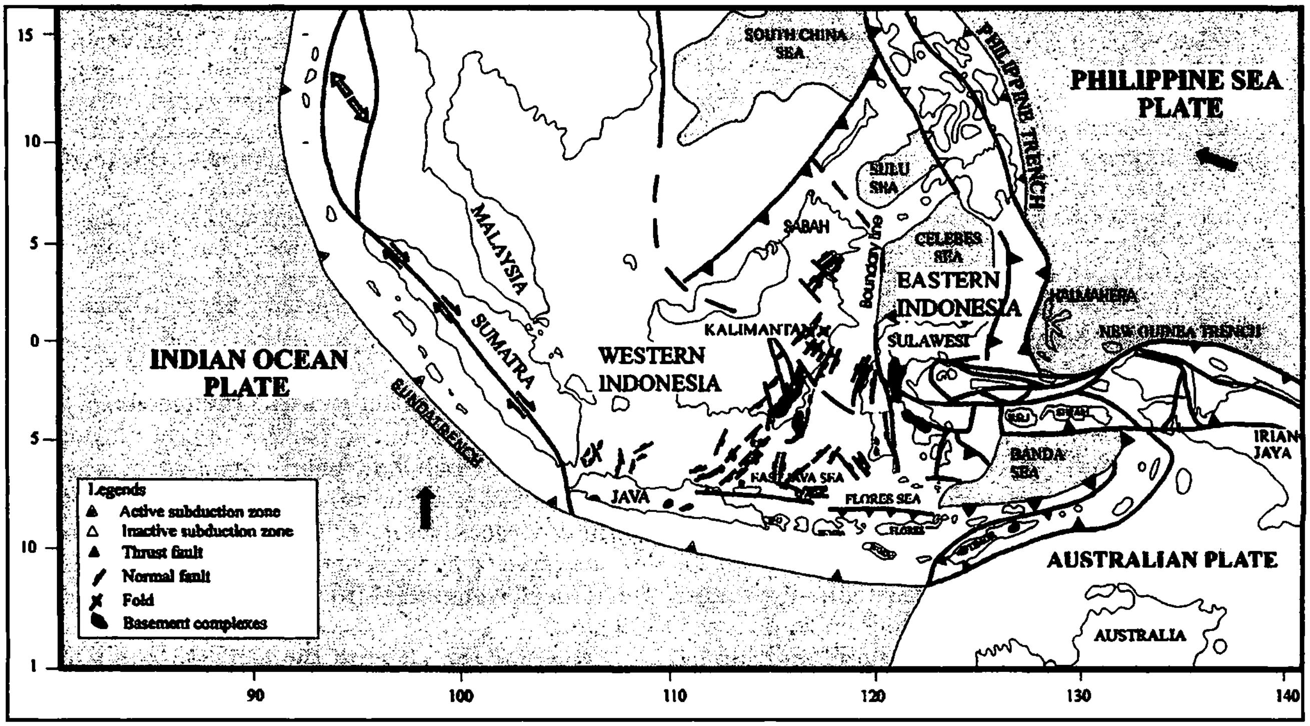

Figure 2. Present-day tectonic setting showing the structural settings in Central Indonesian region consisting of Makassar Strait, Sulawesi and Bone Bay (modified from Hamilton, 1979; Parkinson, 1991; Bransden and Matthews, 1992).

TECTONIC SETTINGS

The Indonesian archipelago is geologically one of the most complex regions of the world, both structurally and stratigraphically. This is because it lies at the triple junction of three large plates; the Indo-Australian Plate, Eurasian Plate and Pacific Plate (Fig. 2). Since the Late Cretaceous the area has been subjected to varying phases of rifting, subduction, volcanism, collision, wrenching and rotation. Although many geologists have studied this area, evolution and histories are still subject to debate.

It is generally accepted that tectonic development during the Late Mesozoic to Early Tertiary caused changes in subduction zone direction, from NE-SW on the Java-Meratus trend to E-W in the south of Java, forming what is called as Central Indonesian region. The region represents a transition between the largely Eurasian elements of Western Indonesia and the Pacific and Australian related elements of Eastern Indonesia. One of the most interesting features in the CIR is the existence of outcrops of deformed pre-Tertiary basement complexes in the West and Central Java, SE Kalimantan and SW Sulawesi, which are similar in age, lithology and structure (Katili, 1978; Hamilton, 1979; Parkinson, 1991). They suggest that these terranes are fragments of a microcontinent, which accreted eastwards and was dismembered in the Late Cretaceous. The eastward migration of a subduction system during the Late Cretaceous and Early Tertiary is suggested by the eastward growth of melange terranes, by the position of the Neogene magmatic arc to the east of the Cretaceous one and by the separation of the Western Arc of Sulawesi from Kalimantan. These events are thought to have been responsible for the formation of structural and basins in the CIR: the Makassar Basin, Sulawesi and Bone Bay. In the Neogene, a period of collision involving a number of microcontinents occurred in eastern Indonesia, and one of the collisions occurred between Banggai-Sula Microcontinent and East Sulawesi. This collision is believed to be responsible for the tectonic and structural development in CIR as seen in the present.

STRUCTURAL SETTINGS

Sulawesi

Sulawesi is known as one of the most complex geology in the world since it is situated in the triple junction of the three large plates; the Indo-Australian, Eurasian and Pacific plates. It consists of four diverging arms named, the South, North, East and Southeast arms in which each of them has very different lithologies and structures with different histories and origins. Therefore, the terminology of tectono-stratigraphic terrane as described by Howell and Jones in 1983 (Hartono and Tjokrosapoetro, 1984) can be applied to Sulawesi. In terms of tectono-stratigraphic terrane, Sulawesi and its vicinity can be divided into four major belts (Fig. 3), they are; the Banggai-Sula Microcontinent (BSM); the Eastern Sulawesi Ophiolite Belt (ESOB); the Central Sulawesi Metamorphic Belt (CSMB) and the Western Sulawesi Plutono-Volcanic Belt (WSPVB). The amalgamation of each terrane involves a series of collision between microcontinents and is represented by suture zone consisting of basement complexes and strike-slip faults.

The major structures seen in Sulawesi are left and right lateral faults (Walanae Fault, Palu-Koro Fault, Matanao Fault, Poso Fault and Balantak Fault), fold and thrust belts (Majene fold Belt; Batui thrust Fault), obduction of the ophiolite in East Arm of Sulawesi and uplifted Quaternary coral reef (see Fig. 3). Some of the faults are related to the boundary of each terrane and some are related to the deformation accompanying the collision. Between WSPVB and CSMB is marked by the presence of Tawaela Graben and Median Line which was used by van-Bemmelen (1949) to separate the Palu Zone (equivalent to WSPVB) and the Poso Zone (equivalent to CSMB).

All the structures as listed above mostly occurred during the Middle Miocene up to Plio-Pleistocene.

Bone Bay

Structural interpretation of Bone Bay has been derived from seismic interpretation and gravity data as well as regional geological data (Guntoro, 1996). Figure 4 shows seismic interpretation in Bone Bay running from north to south (see Fig. 1 for seismic location). The figures show the bay is dominated by normal faults that displace basement faults, except in line IND 07 which shows the oldest sedimentary rocks were folded and is unconformably overlain by the flat sedimentary sequence. In contrast, to the south of this strongly folded sequence is dominated by normal faults. It suggests that when the area in Line IND 07 experienced compressional stress, the southern region experienced extensional stress. In Line IND-116, at the western part, shows the presence of a trough with the water-depth in access of 3,000 m and is interpreted as a remnant subduction of Early Tertiary. The major unconformity as seen in line IND 07 is interpreted to be correlated with the major tectonic event in Sulawesi occurred during the Middle Miocene (van-Leeuwen, 1981). Seismic interpretation constrained by gravity data indicate the extent and orientation of structure in Bone Bay in NNW-SSE orientation (Fig. 5), and this orientation is the same with those in Sulawesi. Gravity data and models suggested that the crust beneath Bone Bay experienced crustal thinning and the formation of oceanic crust (Guntoro, 1996).

Makassar Strait

Structural interpretation of Makassar Strait has been derived from seismic reflection profiles and gravity data (Guntoro, 1997). The bathymetry of Makassar Strait indicates that the strait is separated by two major depressions which is named North and South Makassar basins (see Fig. 1).

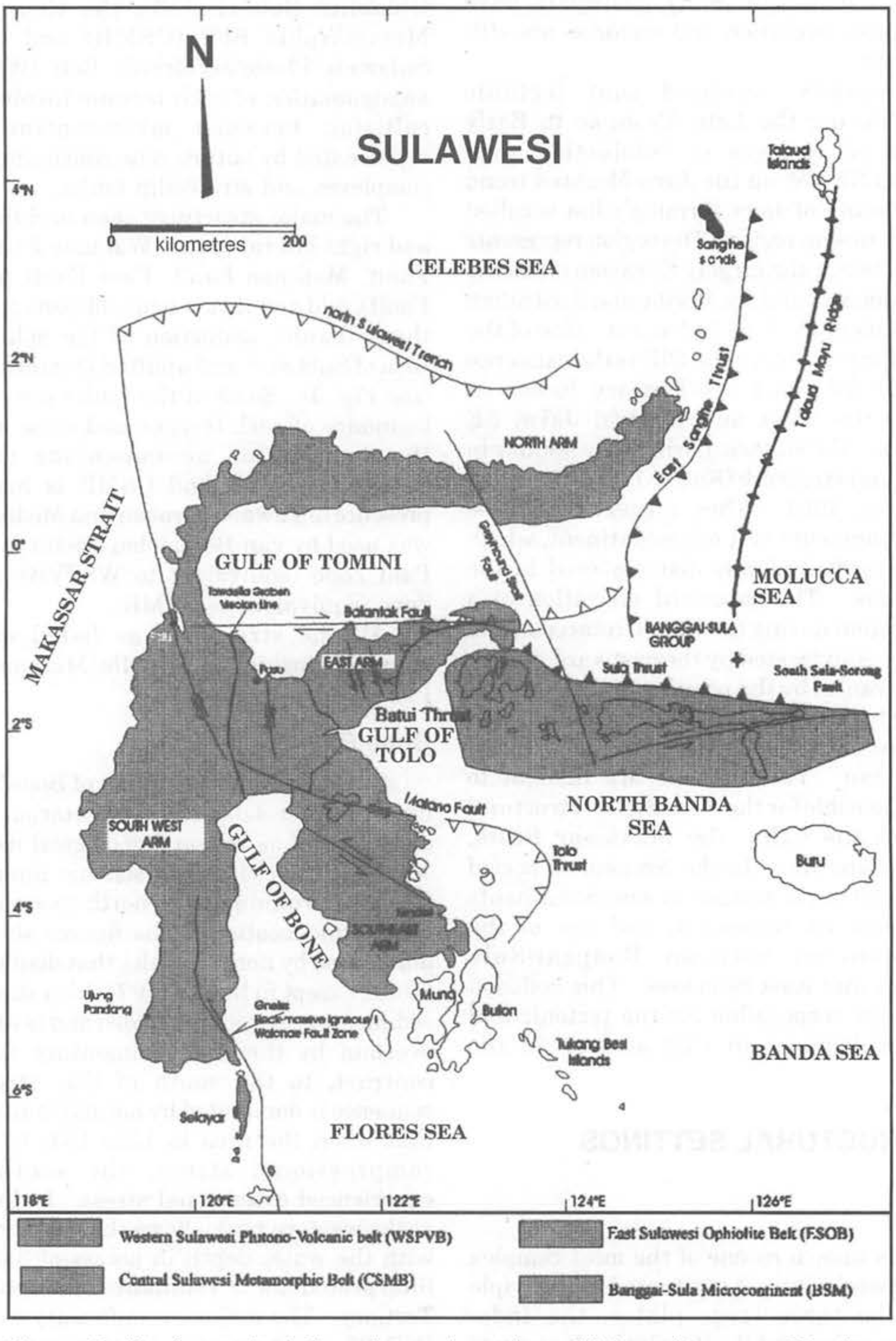

Figure 3. The four major belts and tectonic settings of Sulawesi (sources: Hamilton, 1979; Silver *et al.*, 1983; Daly *et al.*, 1987, 1991; Simanjuntak, 1990; Parkinson, 1991).

Seismic interpretations of line PAC 201 and PAC 202 in the North and South Makassar basins show that the basin is controlled by graben-like structure as a result of extensional processes (Fig. 6). This is also supported by the result of seismic interpretation in other parts of Makassar Strait by Burollet and Salle (1981) and Situmorang (1982). However, the western and eastern sides of the North and South Makassar basins have different structural settings. The North Makassar Basin is occupied by active reverse faults on both sides, whereas the south Makassar Basin is still occupied by normal faults as occur in the central of the basin. Figure 7 shows a series of reverse faults dipping to the east and west and displacing up to the youngest sediments (Pertamina, 1985). On Line PAC 201 of the eastern segment (Fig. 6), a series of reverse faults are present dipping to the east and these mostly do not displace the youngest sequence. In contrast, the eastern and western parts of South Makassar Basin are dominated by extensional faults (see Fig. 6 on Line PAC 202, and Fig. 7).

On line PAC 201 and 202, the time of extensional is indicated by Horizon H2 (see Fig. 6) which is in Late Eocene (Guntoro, 1997). Whereas, the timing of compressional tectonics happened in the eastern

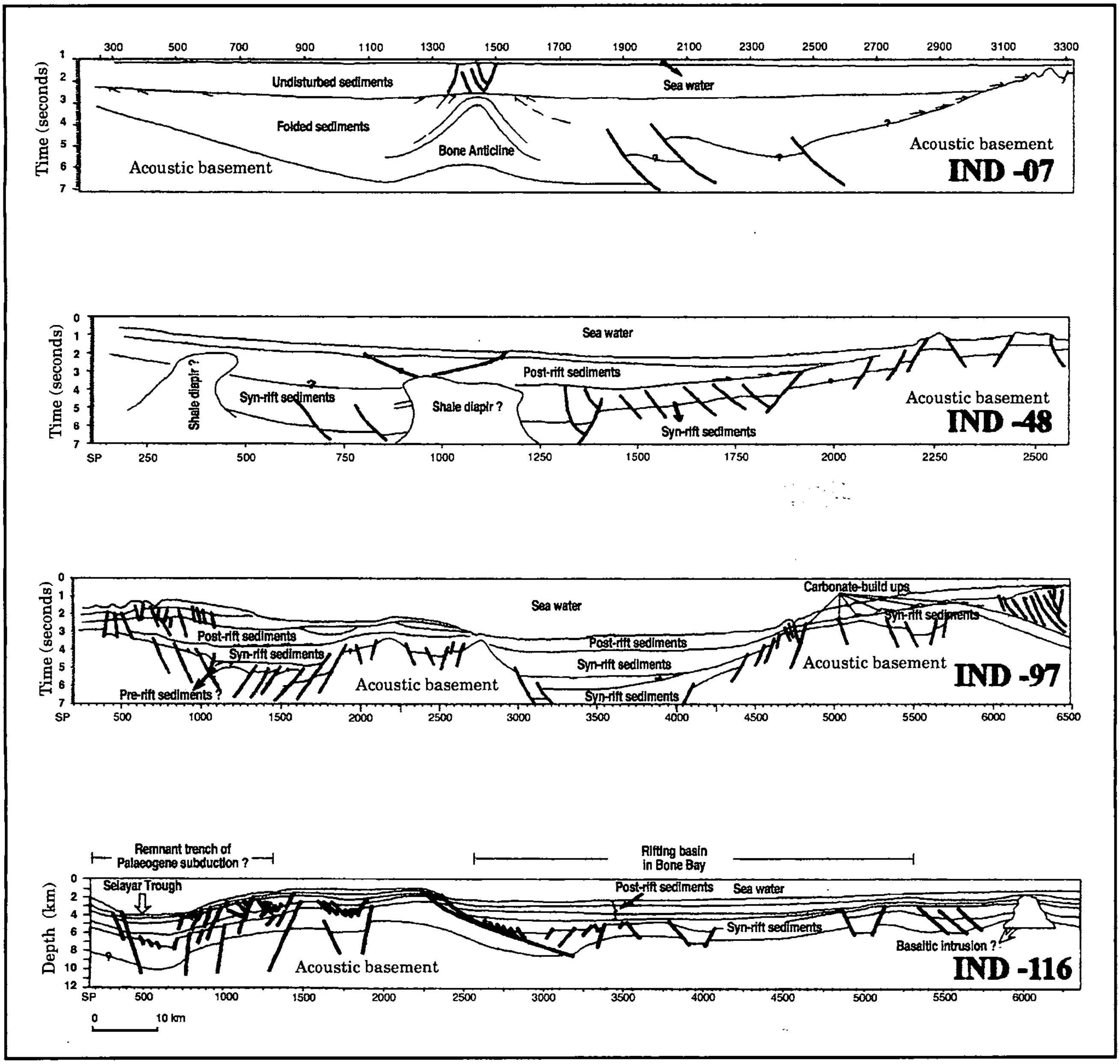

Figure 4. Seismic interpretation of Line IND 07, IND 48, IND 97 and IND 116 showing the presence of extensional basin in Bone Bay. Arrows mark cycle termination on onlap, which provide criteria for recognition of sequence boundaries.

and western side of North Makassar Strait indicated by Horizon H5 is interpreted occur during Early to Middle Miocene (Guntoro, 1997). This leads to the interpretation that there are more than one successive events influencing the tectonics in the Makassar Strait, and the event in Middle Miocene had significant effect to the area.

TECTONIC IMPLICATIONS

The timing of structural event influencing structural settings in Central Indonesian Region seems occur dominantly during Middle Miocene to Plio-Pleistocene as described above. This is also the time of the collision of Banggai-Sula Microcontinent (BSM) to Sulawesi along the Sorong Fault Zone (SFZ). The movement of SFZ is suggested to be responsible for the emplacement of BSM in collision contact with East Sulawesi. Hall (1996) suggested that the Sorong Fault Zone system occur during the major change in plate boundaries at the early Miocene as a result of arc-continent collision of the Australian margin with the Philippine Sea Plate. The SFZ initiated the movement of continental fragments westward and some microcontinets collided with Sulawesi. The SFZ has length more than 1,500 km extending from the bird's head of Irian Jaya in the east and the island of Sulawesi in the west (see Fig. 2).

The effect of this collision to the structural development in CIR is explained using the extrusion model of Tapponnier *et al.* (1982) which had been used to explain the structural settings of mainland eastern Asia with respect to the indentation of India continent to Eurasia in the Eocene (Fig. 8). The collision of BSM through the movement of SFZ to the East Sulawesi in the Middle Miocene formed the formation of Kolokolo melange and the Batui-Balantak faults. As a result of this collision caused compression in the north of Bone Bay (as seen in Line IND 07) and extension in the south of Bone Bay (as seen in lines IND 48, IND 97 and IND 116). Whereas the effect in Sulawesi is comparable with the structural patterns formed in the model in which a series of strike-slip fault occur, such as Walanae Fault, Palu-koro Fault, Matano Fault and Poso Fault. Later on, the continuous movement of BSM has caused displacement and rotation between Walanae and Palu-Koro faults. The clockwise rotation of western arc of Sulawesi, as suggested by Sasajima *et al.* (1981), accommodated the opening of Bone Bay. At the same time due to the clockwise rotation of Sulawesi caused compressional in the north Makassar Basin reactivated the Eocene extensional faults. The further effect of the collision led the metamorphic belt of Central Sulawesi thrusting westward on west Sulawesi and uplifted to form mountain range of nearly 3,000 m. Overthrusting resulted in the formation of a Majene fold and thrust belt of Tertiary sediments in the West Sulawesi. The stress probably continues westward to the Makassar Strait (Simanjuntak, 1990; Bergmant *et al.*, 1996).

CONCLUSIONS

The collision of BSM to the East Sulawesi occurred in the Middle Miocene, and the effect of the collision caused the formation of structural settings in CIR as follows;

1. Compressional and extensional tectonic in Bone Bay, and later on caused the opening of Bone Bay.
2. The formation of complex strike-slip fault of Sulawesi and some other fold and thrust belts as well as uplifted coral reefs.
3. The inversion structure in eastern and western sides of North Makassar Basin by reactivating Eocene extensional basin.

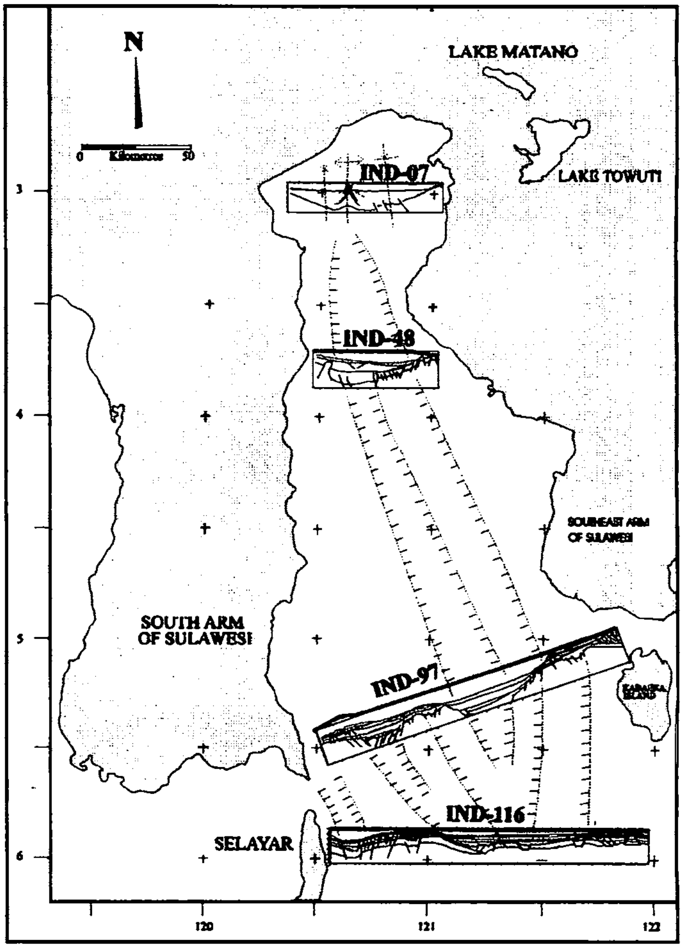

Figure 5. Possible correlation of seismic structures in Bone Bay constrained from seismic and gravity data.

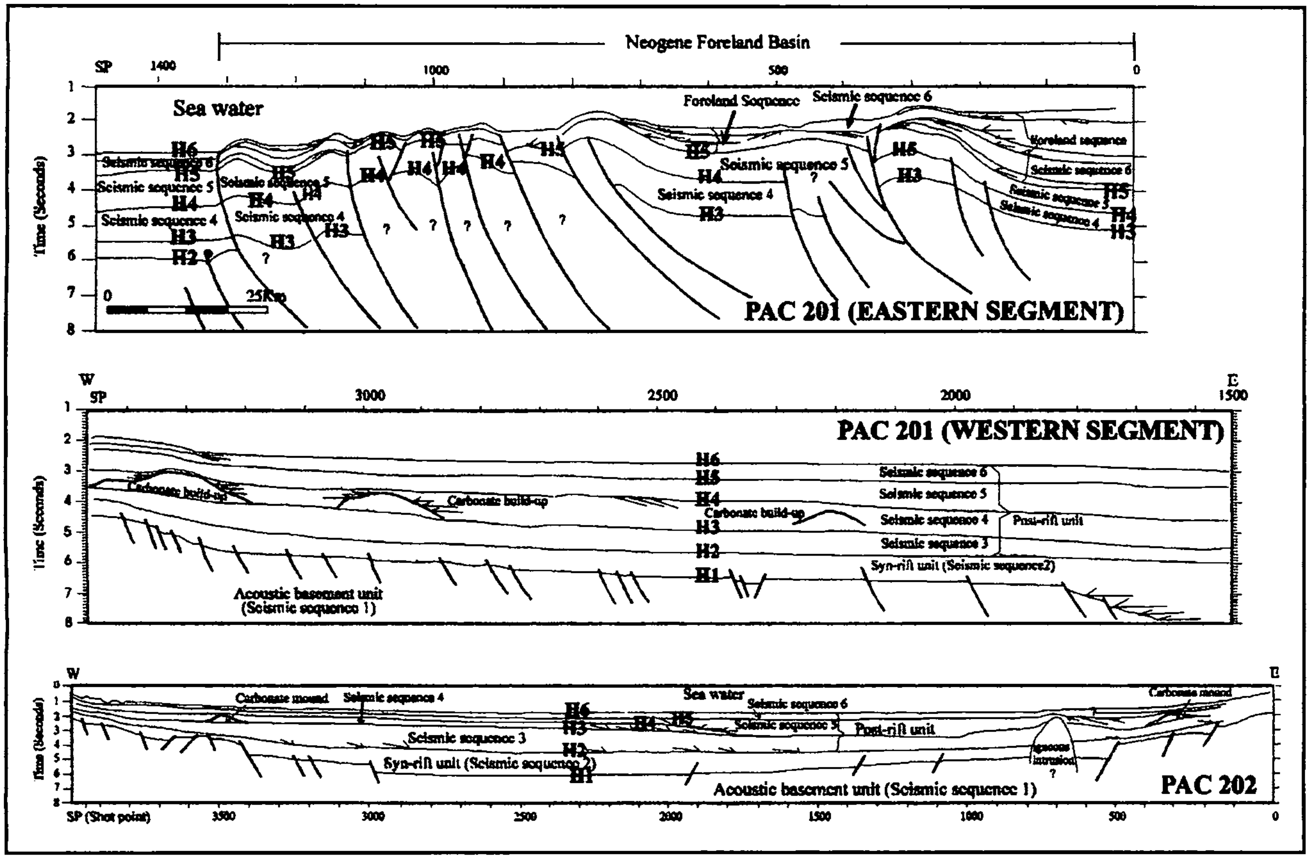

Figure 6. Seismic interpretation of line PAC 201 & 202 showing basement faults, suggesting extensional basin, and thrust faults forming foreland basin. Arrows mark cycle terminations on onlap, downlap and toplap which provide criteria for recognition of sequence boundaries. Letters H1–H6 designate the tops of seismic sequences.

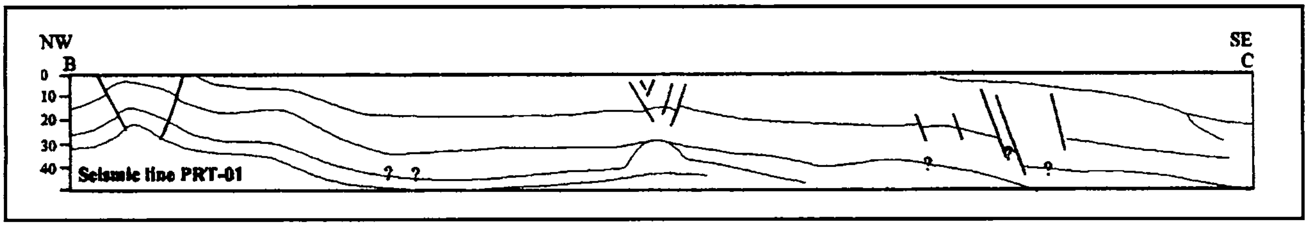

Figure 7a. Seismic interpretation in the westernside of North Makassar Basin showing the compressional zone (Pertamina, 1985).

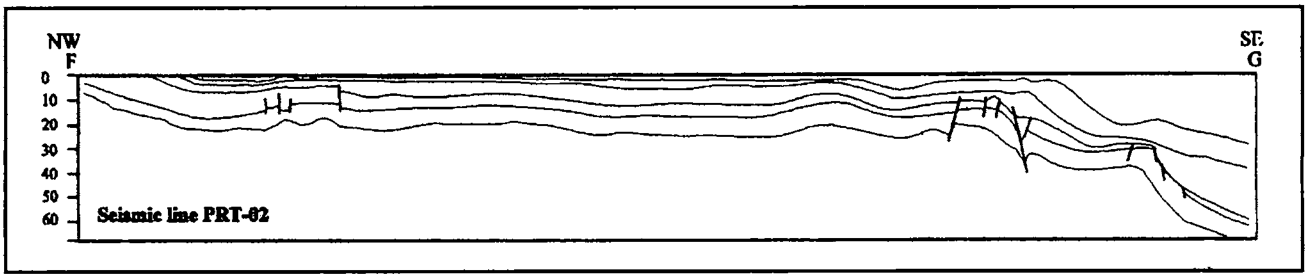

Figure 7b. Seismic interpretation in the westernside of South Makassar Basin showing the extensional zone (Pertamina, 1985).

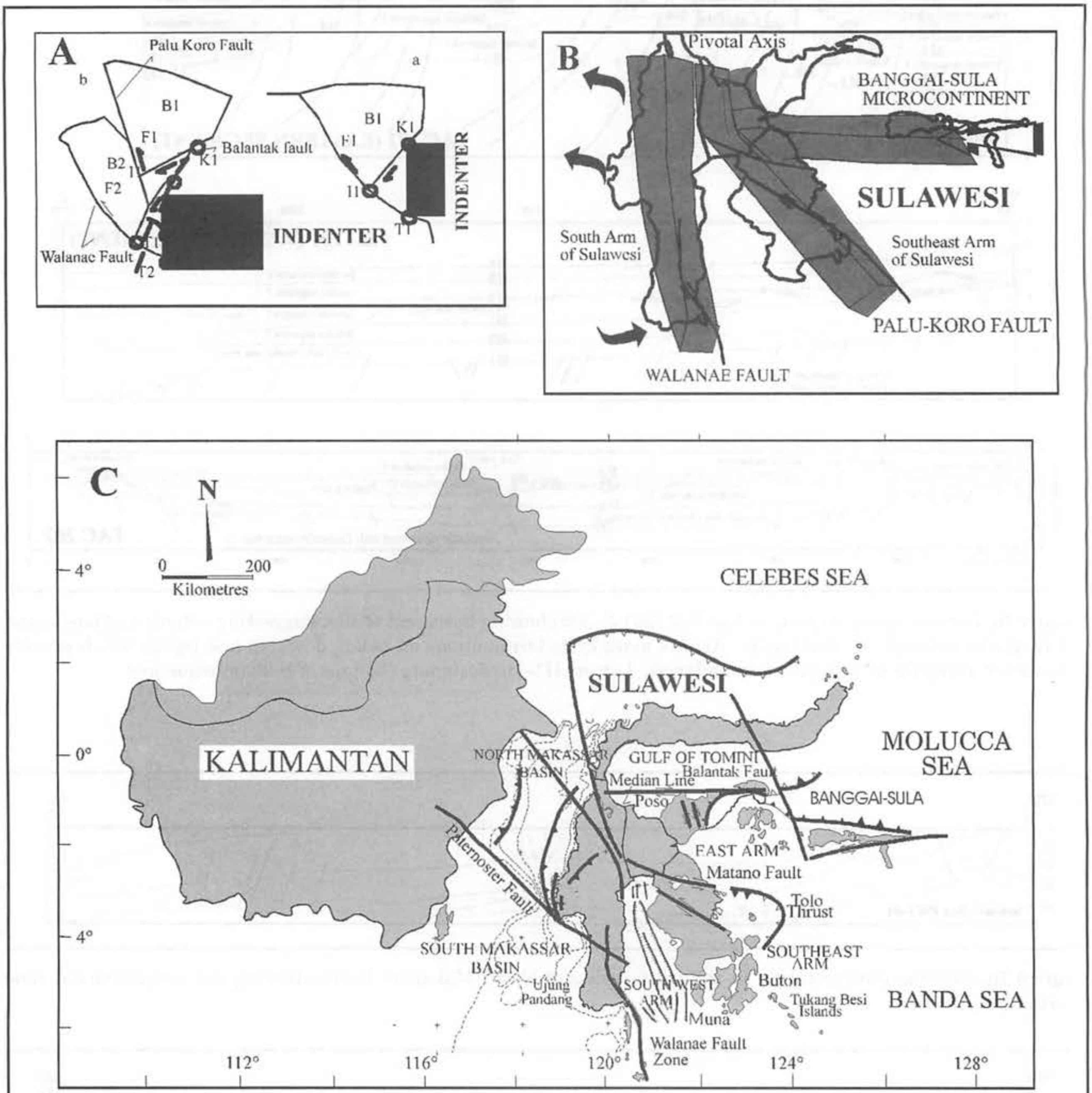

Figure 8. (A) A cartoon showing the indentation model of Tapponnier *et al.* (1982) showing the sequence of faults to accommodate the indentation. (B) The same model is applied to the collision between Sulawesi and Banggai-Sula microcontinent causing structural development in Sulawesi, the opening of Bone Bay and anticlockwise of the North Arm of Sulawesi forming a series of thrust faults in eastern and western North Makassar Basin as can be seen in (C).

ACKNOWLEDGEMENT

The author would like to thank the VICO INDONESIA Company for sponsoring the author to present this paper to the GEOSEA Conference 98 in Kuala Lumpur.

REFERENCES

BERGMAN, S.C., LOFFIELD, D.Q., TALBOT, J.P. AND GARRAD, R.A., 1994. Late Tertiary tectonic and magmatic evolution of SW Sulawesi and the Makassar Strait: Evidence for a Miocene continental collision. *In:* R. Hall and D.J. Blundell (Eds.), Tectonic Evolution of Southeast Asia. *Geological Society Special Publication No. 106.*

BRANSDEN, P.J.E. AND MATTHEWS, S.J., 1992. Structural and stratigraphic evolution of the East Java Sea, Indonesia. *IPA Proceeding, Annual Convention 21st, Vol. 1*, 417–453, Oct.

BUROLLET, P.F. AND SALLE, C., 1981. Seismic reflection profiles in Makassar Strait. *Spec. Publ. Geol. Res. Dev. Centre, 2*, 273–276, 1981.

DALY, M.C., HOOPER, B.D.G. AND SMITH, D.G., 1987. Tertiary plate tectonics and basin evolution in Indonesia. *IPA Proceeding, 16th Annual Convention, Jakarta*, 399–428.

DALY, M.C., COOPER, M.A., WILSON, I., SMITH, D.G. AND HOOPER, B.D.G., 1991. Cenozoic plate tectonics and basin evolution in Indonesia. *Marine and Petroleum Geology, 8(1)*, 1991, 2–21.

GUNTORO, A., 1996. Seismic Interpretation and Gravity Models of Bone Bay in relation to Its Evolution. *IAGI Proceeding, 25th, Bandung*, 9–12 December 1996.

GUNTORO, A., 1997. The formation of Makassar Strait in relation to the evolution of the separation between Southeast Kalimantan and Southwest Sulawesi. In *Tectonics, Stratigraphy & Petroleum Systems Workshop*, at Universiti Brunei Darusalam, 22–25 June 1997.

HALL, R., 1996. Reconstructing Cenozoic SE Asia. *In:* R. Hall and D.J Blundell (Eds.), Tectonic Evolution of Southeast Asia. *Geological Society Special Publication No. 106.*

HAMILTON, W., 1979. Tectonics of the Indonesian region. *US Geol. Surv. Prof. Paper 12078.*

HARTONO, M.H.S. AND TJOKROSAPOETRO, S., 1984. Preliminary account and reconstruction of Indonesia terranes. *IPA Proceedings, 13th Annual Convention, Jakarta.*

KATILI, J.A., 1978. Past and present geotectonic position of Sulawesi, Indonesia. *Tectonophysics, 45 (1978)*, 289–322.

PARKINSON, C.D., 1991. *The Petrography Structure and Geologic History of the Metamorphic Rocks of Central Sulawesi.* Ph.D. Thesis, University of London.

PERTAMINA, 1985. *Hydrocarbon Potential of western Indonesia.* Internal Report (Unpubl.).

SASAJIMA, S., NISHIMURA, S., OTOFUJU, Y., HIROOKA, K., LEEUWEN, T.H. AND HEHUWAT, F., 1981. Paleomagnetic studies combined with fission-track dating on the western arc of Sulawesi, East Indonesia. *The Geol. and Tect. of East. Ind, Geol. Res. and Dev. Cent., Spec. Publ. No. 2*, 305–311, 1981.

SILVER, E.A., REED, D. AND MCCAFFREY, R., 1983. Back-arc thrusting in the Eastern Sunda arc, Indonesia: A consequence of arc-continent collision. *J. Geophys. Res., 88(B9)*, 7429–7448, 1983.

SIMANDJUNTAK, T.O., 1990. Sedimentology and tectonics of the collision complex in the east arm of Sulawesi, Indonesia. *Geol. Indon., 13(1)*, 1–35.

SITUMORANG, B., 1982. *The formation and evolution of the Makassar Basin, Indonesia.* Ph.D. Thesis (Unpubl.), Univ. London, 313p.

TAPPONNIER, P., PELTZER, G., LE DAIN, Y.Y., ARMIJO. R. AND COBBING, P., 1982. Propagating extrusion tectonics in Asia: new insights from simple experiments with plasticene. *Geology 10*, 611–616.

VAN BEMMELEN, R.W., 1949. *The Geology of Indonesia.*

VAN LEEUWEN, M.TH., 1981. The Geology of Southwest Sulawesi with special reference to the Biru area. *The Geology and Tectonics of Eastern Indonesia, Res. and Dev. Cent., Spec. Publ. No. 2*, 1981, 277–304.

Manuscript received 1 December 1998