The Geology and Tectonics of Eastern Indonesia, Geological Research and Development Centre, Spec. Publ. No. 2, 1981, pp. 321–325

SEISMIC REFRACTION STUDIES IN THE EAST ARM, SULAWESI – BANGGAI ISLANDS REGION OF EASTERN INDONESIA

R. McCaffrey, E.A. Silver
Earth Sciences Board University of California
Santa Cruz, CA 95064

R.W. Raitt
Scripps Institution of Oceanography,
A–005 La Jolla, CA 92093

ABSTRACT

Seismic refraction profiles run in the structurally complex region east of the East Arm of Sulawesi, reveal an extensively block faulted basement overlain by 1 to 2 km of low seismic velocity sediments. Constant velocity layer interpretations of travel-time curves show a series of fault bound blocks within crust of the Gorontalo Basin successively stepped up tpward the East Arm of Sulawesi. This faulting is interpreted to be part of a wide zone of deformation produced by the late Cenozoic collision of the Banggai Islands continental fragment with the eastern Sulawesi island-arc.

INTRODUCTION

Eastern Indonesia marks a region of convergence between four major lithospheric plates: the Australian, Philippine, Pacific and Asian plates. As a consequence, it is also an area of complex structure and tectonics dominated by many presently active and completed collision events. One such event is the late Cenozoic collision between the Banggai – Sula Islands continental fragment and the eastern Sulawesi island-arc. Instabilities produced by the introduction of this buoyant lithospheric element into the trench-arc system probably resulted in cessation of subduction and may have assisted in the emplacement of the large ultramafic and melange belt of eastern Sulawesi (Silver *et al.*, 1978; Hamilton, 1979).

The pairing of volcanic and schist belts on Sulawesi is consistent with westward subduction beneath the Sulawesi island-arc prior to emplacement of the large ultramafic sheet in eastern Sulawesi (Fig. 1). The east–west trending part of the North Arm and the entire South Arm of Sulawesi are comprised largely of volcanics (predominantly calc-alkaline) active from about lower Miocene to Quaternary time (Sukamto, 1975a). This L-shaped zone of volcanics extends northward into the Sangihe volcanic arc which is the presently active western edge of the Molucca Sea collision zone. The central portion of Sulawesi and the southern half of the Southeast Arm are composed of a schist belt which increases in metamorphic grade westward. The ultramafic sheet, which is found on most of the East Arm and the northern half of the Southeast Arm, is largely massive peridotite and locally surrounds surface exposures of melange and Cretaceous and Tertiary limestone. The gravity field over the northern part of the Southeast Arm gives evidence for the westward thickening of the ultramafic body and infers a volumetrically larger body of low density melange than is evident from geologic mapping (Silver *et al.*, 1978). A full ophiolite suite is reported to be exposed on the East Arm (Brouwer, 1947; Kundig, 1956).

The eastern edge of the Sulawesi ultramafic sheet is bounded by the Banggai – Sula Islands, a slice of continental crust thought to have been faulted

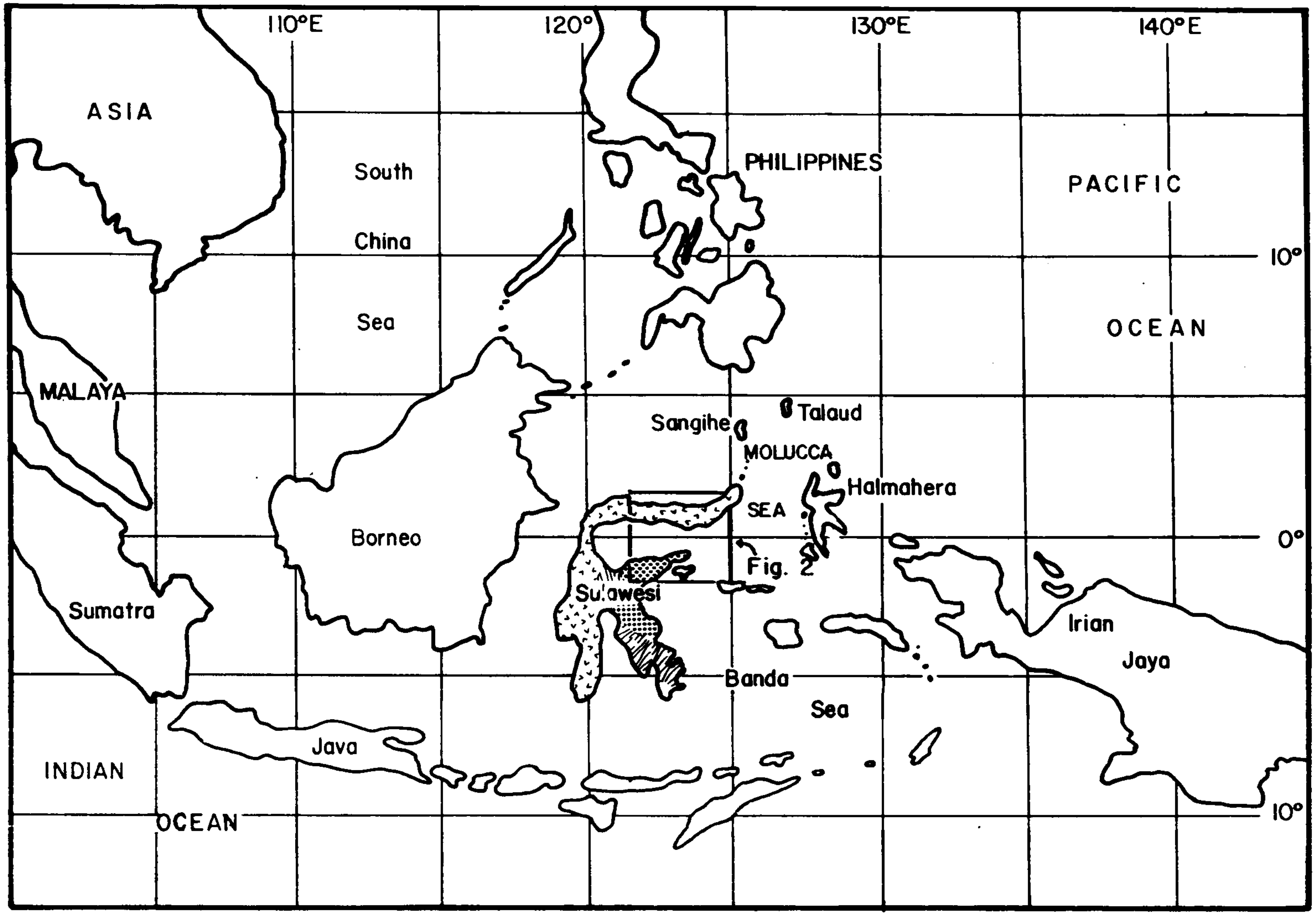

Fig. 1 : Map of Indonesia showing location of volcanic (v), schist (wavy lines) and ophiolite (stippled pattern) belts on Sulawesi. The small box enclosing the north and east arms of Sulawesi outlines the area shown in Figure 2.

westward from Irian Jaya followed by collision with the Sulawesi island-arc (Visser & Hermes, 1962). In this way, the injection of the Banggai Islands into the subduction zone as an elevated feature on the downgoing plate may have provided the mechanism for emplacement of the large ophiolite on Sulawesi (Silver *et al.*, 1978).

Recent studies of this complex collision zone have included gravity traverses and geologic mapping on Sulawesi (Silver *et al.*, 1978), marine seismic reflection profiling (Silver, 1981), and to be presented here, seismic refraction profiling. A detailed tectonic map of eastern Sulawesi and environs incorporating the latest marine and land geophysical data has been presented by Silver (1981).

SEISMIC REFRACTION INTERPRETATION

Three marine seismic refraction profiles were run in the East Arm – Banggai Islands region during INDOPAC Leg 10 (February, 1977) on board the R/V *Thomas Washington* of Scripps Institution of Oceanography (Fig. 2). Two of the profiles (10–9 and 10–11) are open-ended profiles using multiple drifting sonobuoys and one (10–10) is a reversed profile employing moored sonobuoys.

Due to the complexity of the observed travel-time curves, we have interpreted these profiles by a graphical ray tracing technique. Interpreting travel-time curves by ray tracing allows a better fit to irregular profiles recorded in this area of extensive faulting than does plane-layer interpretations. The method is described further by McCaffrey *et al.* (in press).

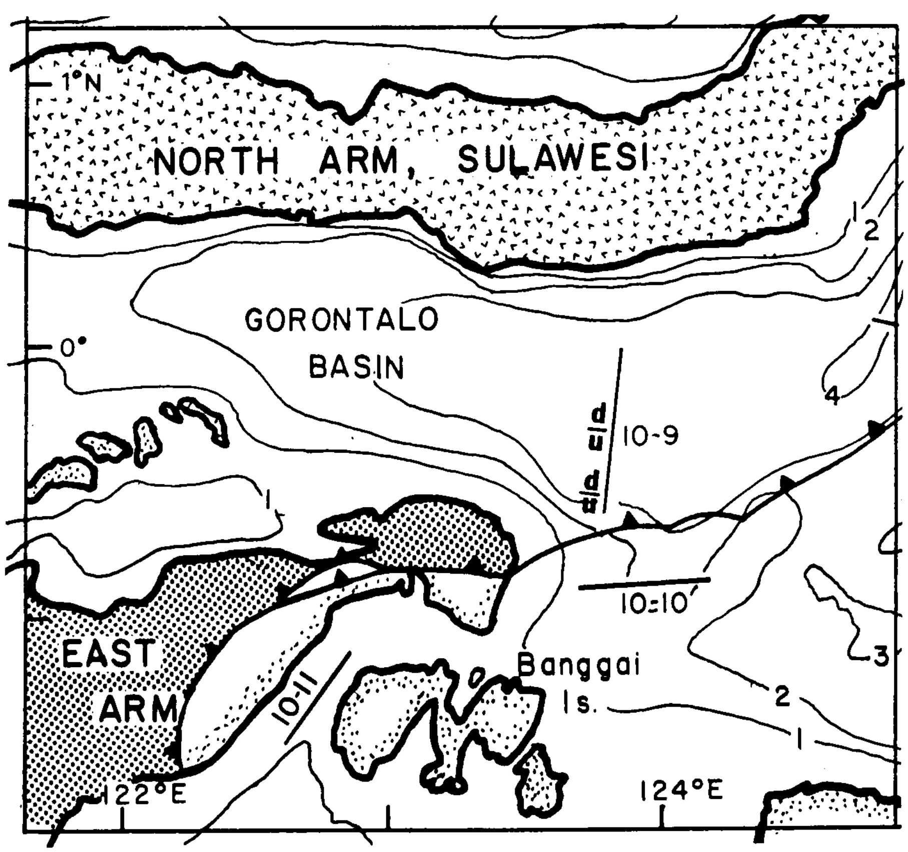

Fig. 2 : Locations of refraction profiles with simplified geologic map of East Arm, Sulawesi. Stippled pattern shows ophiolite belt and heavy line through East Arm is Batui Thrust (teeth on upper plate). u (up) and d (down) give relative displacement on faults crossed by line 10–9.

The irregularity of structure north of the Banggai Islands (Fig. 2) is shown by interpretations of the perpendicular profiles 10–9 and 10–10 (Fig. 3). Two layers are inferred in structure beneath unreversed multiple sonobuoys line 10–9 with a masked sediment layer (assumed velocity of 1.9 km/s) overlying a north-dipping 6.0 km/s basement. Refraction line 10–9 appears to cross two major faults in basement, each of which step up to the south by about 0.6 km. Bathymetry roughly parallels basement in this profile, with the sediment layer delay time typically being between 2.6 and 3.0 seconds of two-way vertical travel-time. A single channel reflection profile 30 km to the east of line 10–9 shows these upper sediments to be flat-lying with a thickness of 1.5 second of two-way travel-time, below which reflectors appear to be chaotic (E.A. Silver, unpublished data).

Major faulting is also interpreted to be predominant in crustal structure beneath reversed profile 10–10. From 12 to 30 km along this profile, basement, overlain by a 1 to 3 km thick sedimentary section, is downthrown by 0.6 to 0.8 km relative to the two adjacent blocks. At distances greater than 36 km from the western end of line, basement is downthrown by 1.2 km. A deeper sediment layer with apparent velocity of 2.4 km/s appears to be present at the eastern end of this profile. The velocity of the higher sediment layer is controlled by refractions from bathymetry and the basement velocity is controlled by reversed coverage.

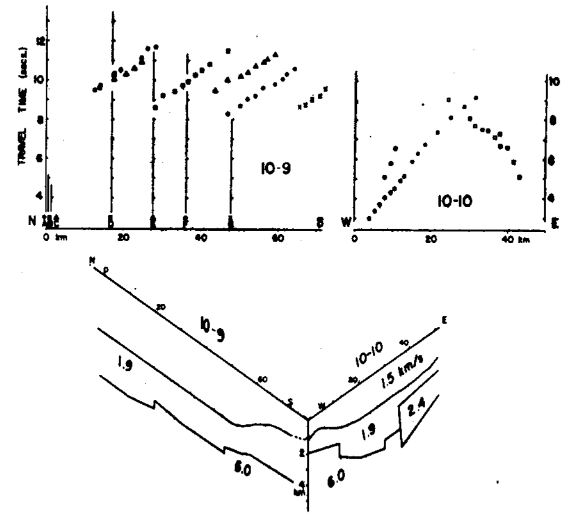

Fig. 3. Refraction travel time plots and interpretations for lines 10–9 and 10–10. Block diagrams shows interpretations of the nearly perpendicular profiles. Positions of receiving buoys are designated by time axes and a separate symbol is used to designate arrivals for each buoy.

Between the East Arm of Sulawesi and the Banggai Islands, we ran a short (40 km) open-ended profile, 10–11 (Fig. 4). Here we interpret thin (1.0–1.3 second of two-way travel-time), masked sediments overlying a 6.5 km/s layer, probably granitic basement of the Banggai – Sula Islands complex (Sukamto, 1975b).

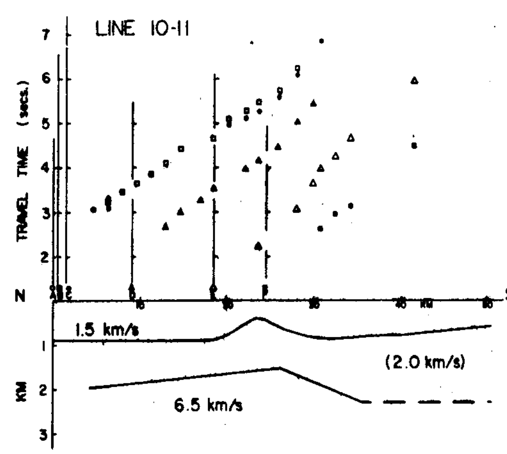

Fig. 4 : Refraction travel time plot and interpretation for line 10–11. Symbols are as described in Fig. 3.

DISCUSSION

Reflection profiles run east of the East Arm of Sulawesi have been interpreted by Silver (1980, Fig. 2) as indicating a major zone of thrust faulting (Batui Thrust) between the Gorontalo Basin and Banggai – Sula Islands continental fragment (Fig. 1). . The southern edge of the Gorontalo Basin crust is uplifted along this fault zone and may crop out on the East Arm of Sulawesi. Refraction line 10–9 shows shallowing of basement underlying the Gorontalo Basin towards the Batui Thrust by block faulting with block sizes on the order of several tens of kilometers long. This southward shallowing and faulting of Gorontalo Basin crust may be attributed to the attempted subduction of continental material beneath higher density oceanic lithosphere of the Gorontalo Basin. Faulting within the overriding oceanic plate away from the main thrust zone may have been an important factor in facilitating subsequent uplift of the ophiolite on Sulawesi.

Basement faulting due to the collision between the Banggai Islands and Gorontalo Basin crust extends to the south of the Batui Thrust (line 10–10) where reflection profiles have also shown extensive deformation due to the proximity of the Sorong and Sula fault zones (Silver, 1981). Basement of the Banggai–Sula Islands complex between the Banggai Islands and East Arm, Sulawesi (line 10–11), gives a velocity typical of continental crust and appears to be relatively undisturbed.

REFERENCES

Brouwer, H.A., 1947. *Geological exploration in the island of Celebes, Geological Summary and Petrology*. North Holland Publishing Company, pp. 346.

Hamilton, W., 1979. Tectonics of the Indonesian region. *U.S. Geo. Surv. Proc. Paper 1078*, pp. 245.

Kundig, E., 1956. Geology and ophiolite problems of east Celebes. *Verhand. Kon. Ned. Geol. Mijnbouw. Genoot.*, Geol. Ser., v. 16, 210–235.

McCaffrey, R., E.A. Silver & R.W. Raitt, in press. Crustal structure of the Molucca Sea collision zone, Indonesia. *In* D.E. Hayes (ed.): Tectonic/Geologic Evolution of Southeast Asia. A.G.U. Monograph.

Silver, E.A., Y. Joyodiwiryo & R. McCaffrey, 1978. Gravity results and emplacement geometry of the Sulawesi ultramafic belt, Indonesia. *Geology*, 1980, 6, 527–531.

Silver, E.A., 1981. A new tectonic map of the Molucca Sea and East Sulawesi, Indonesia, with implications for hydrocarbon potential and metallogenesis. *In:* A.J. Barber & S. Wiryosujono (eds). *Geology and Tectonics of Eastern Indonesia.* G.R.D.C., Bandung, Spec. Publ. No.2, 343–347.

Sukamto, R., 1975a. The structure of Sulawesi in light of plate tectonics. In *Reg. Conf. Geol. and Min. Res. SE Asia.* Association of Indonesian Geologists, Jakarta pp. 25.

––––––, 1975b. Geologic map of Indonesia. Sheet 8, Ujung Pandang (Direktorat Geologi, Bandung).

Visser, W.A. & J.J. Hermes, 1962. Geologic results of exploration for oil in Netherlands, New Guinea. *Verhand. Kon. Ned. Geol. Mijnbow. Genoots.*, Geol. Ser., v. 20, 1–265.