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# Preliminary Results of the 1982 Microearthquake Survey in Nusa Tenggara Timur, Indonesia

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ABSTRACT

From late June until the middle of September, 1982, we operated portable seismographs on the islands of Flores, Timor, Adonara, Lembata, Pantar, Alor, and Savu in Nusa Tenggara Timur, eastern Indonesia. During this period, approximately 2000 earthquakes were recorded of which 460 were locatable and occurred near the seismograph network. Many of the events were shallow (less than 50 km depth) although there was a concentration of activity in the 70 – 200 km depth range at about latitude 9° S and longitude 124° E. This concentration forms a 45° northwest dipping seismic zone and occurs within the lithosphere of the Indian Ocean – Australian plate subducted at the Java trench – Timor trough subduction system. Levels of seismic activity east of about 124.5° E seem to be depressed possibly owing to the partial subduction of continental crust in that area. Seven earthquakes of magnitude 5.0 or greater occurred near the network during the survey period. Three of these occurred at shallow depth beneath western Flores including the two events of August 6 that caused considerable damage. Other large events included two near 9° S, 124° E, one north of Savu Island and one deep (570 km) event about 100 km north of western Flores.

## INTRODUCTION

Most of the present tectonic complexity observed in southeast Indonesia is due to the northward movement of the Australian continental mass relative to southeast Asia as part of the Indian Ocean plate and its encroachment on the Indonesian islands. The presence of continental crust beneath the Sunda forearc region north of the Timor trough produces a marked change in the distribution of earthquakes, volcanoes, and geologic structures along this portion of the convergent margin. West of the Savu Sea, where oceanic crust is being subducted, tectonic features such as earthquakes and volcanoes lie in belts parallel to the Java trench. East of the Savu Sea where continental crust is underthrusting the forearc, however, the line of active volcanoes is interrupted, sismicity occurs at very low levels, and the width of the forearc varies drastically along strike.

In this paper we present locations of microearthquakes recorded by a 10 week long temporary seismograph network around the Savu Sea during 1982. Our aims are to characterize the process of collision of a continental margin with an island arc and to describe more accurately the distribution of earthquakes in the Nusa Tenggara Timur region.

## THE FIELD PROGRAM

As a cooperative effort between the Massachusetts Institute of Technology (USA), Geological Research and Development Centre (Bandung), and Institute of Meteorology and Geophysics (Jakarta), a network of portable seismographs was installed in Nusa Tenggara Timur for approximately 10 weeks in 1982. The first station was installed on June 25 and the last removed on September 16. The locations of the recording sites are given in Figure 1 and Table 1 and the operation dates are displayed in Figure 2. All instruments used short-period vertical seismometers and, in addition, station Adonara operated one horizontal component (N–S). Portable instruments used include models Sprengnether MEQ–800, Kinemetrics PS–1A, and Geotech Portacorder. Additional arrival time data were acquired at the permanent Indonesian seismograph stations at Kupang, Timor (KUG), Waingapu, Sumba (WSI), Ujung Pandang, Sulawesi (MKS), and

Table 1. *Coordinates of Temporary Stations*

| *Station* | *Latitude* °S ' | *Longitude* °E ' |
|---|---|---|
| Ende | 8 49.1 | 121 38.7 |
| Maumere | 8. 38.0 | 122 12.5 |
| Larantuka | 8 16.2 | 122 59.5 |
| Adonara | 8. 23.1 | 123 9.4 |
| Hadekawa | 8 23.0 | 123 32.2 |
| Pantar | 8 23.7 | 124 4.9 |
| Mali | 8 8.6 | 124 34.9 |
| Dili | 8 34.9 | 125 34.5 |
| Atambua | 9 5.5 | 124 53.3 |
| Kefamenanu | 9 26.5 | 124 28.5 |
| Niki-niki | 9 48.5 | 124 28.0 |
| Soe | 9 54.4 | 124 18.4 |
| Camplong | 10 3.0 | 123 55.0 |
| Baun | 10 18.5 | 123 40.0 |
| Savu | 10 29.1 | 121 52.2 |

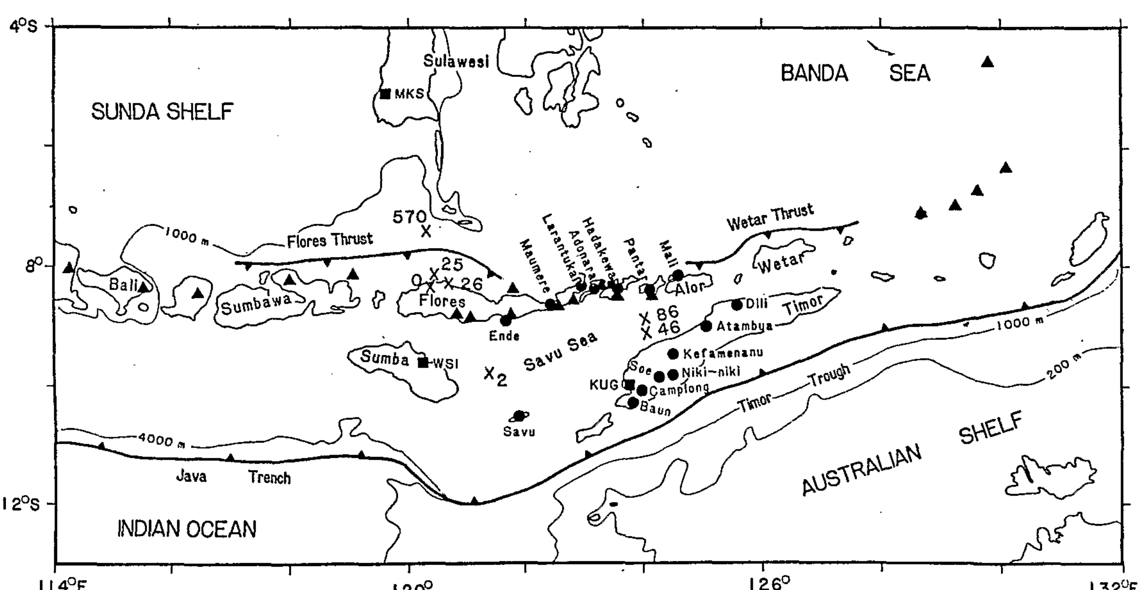


*Fig. 1.* Geographic and tectonic map of southeast Indonesia. Thrust faults are shown as solid lines with barbs on the hanging wall. Position of temporary seismograph stations are shown by solid circles and permanent stations by solid squares. Solid triangles show active volcanoes. X's and associated numbers show epicenters and depths of events of magnitude 5.0 or greater. Bathymetric contours are in metres.

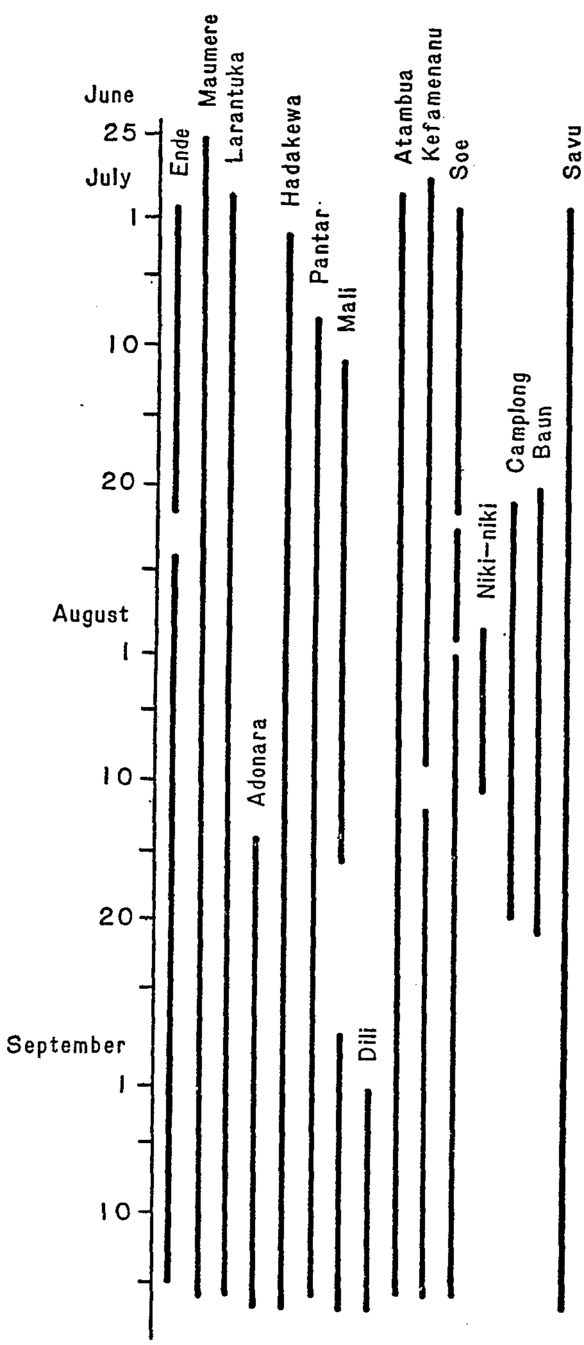


*Fig. 2.* Bar chart showing operation dates for all temporary seismograph stations

Ambon (AAI at 3.9°S and 128.1°E). Time synchronization was obtained by marking the broadcasted Coordinated Universal Time on the seismogram either electronically or manually via the instrument.

## DATA ANALYSIS

Arrival times were picked from the seismograms with the aid of a digitizing table which introduced an error of no more than 0.10 s. Additional errors are in the clock correction (0.05 to 0.3 s) and in determining the onset of the phases (probably less than 0.10 s for local events).

Earthquakes were located with the computer program HYPOINVERSE (Klein, 1978) which uses a layered, flat earth velocity model. We assumed the P wave velocities of Herrin (1968) and a P to S wave velocity ratio of 1.75 . All locations were graded A, B, or C (in order of decreasing reliability) according to root-mean-square error in residuals (RMS), resolution of epicenter and depth, and the distribution and number of stations recording the event, as outlined in Table 2. The uncertainties in the hypocentral locations associated with the above classifications were evaluated by examining the variations in locations of many events (of each classification) due to perturbations in the assumed crustal structure, ratio of P to S wave velocities, and group of stations recording the event. The tests indicate that, for an A classification, the depth is within 8 km and the epicenter is within 5 km. A B rating infers a depth within 15 km and an epicenter within 10 km. The uncertainty associated with the C classification is more difficult to assess because most events of this type fail the requirement that the nearest station be within one or two focal depths of the epicenter.
Nevertheless, these events can have well determined epicenters when they are within the network or located by many stations. In general, the uncertainty in the location increases with decreasing depth and with the distance to the nearest station when the event is outside the area enclosed by the network.

## RESULTS

The locations of all epicenters are shown on Figure 3. Clearly, a large concentration of recorded events occurred south of Pantar island (9°S, 124°E) at depths of 70 – 200 km. Figure 4 shows a view of all hypocenters projected onto an east–west trending vertical plane. East of 119°E, the seismic zone is fairly well defined to a depth of about 200 km and to 300 km between 122° and 124°E. East of 124°E, however, the seismic zone changes character as the majority of events appear to be shallow and there are only 2 events of class B deeper than 100 km. Note that the volcanic chain also terminates at 124°E. The seismic quiescence at intermediate depths in the vicinity of Alor and Wetar is also observed in the long term seismicity pattern described by earthquake locations determined by the International Seismological Centre using data from the World Wide Standardized Seismograph Network (see Cardwell and Isacks, 1978). This quiescence in seismicity and volcanism is probably related to the presence of the Australian continental mass in the subduction zone but the mechanism is not clear.

Hypocenters beneath the eastern Savu Sea reveal a trend of deepening to the northwest (Figure 3). By plotting cross-sectional projections at various azimuths, we have determined that the best aligment occurs at about N25°W (Figure 5). This projection includes all earthquakes within the area enclosed in brackets in Figure 3. In this projection, we observe a dense zone of seismicity dipping to the northwest at an angle of 45° between 70 and

Table 2. *Rating Criteria for Hypocentral Locations.*

| Rating | RMS s | ERH km | ERZ km | # Phases | #S | Nearest Stations | Gap |
|---|---|---|---|---|---|---|---|
| A | ⩾ 0.1, ⩽1.0 | ⩽10 | ⩽10 | ⩾7 | ⩾1 | ⩽ depth | ⩽ 180° |
| B | ⩽ 2.0 | ⩽10 | ⩽30 | ⩾5 | – | ⩽2 x depth | ⩽ 270° |
| C | ⩽ 3.0 | ⩽99 | ⩽99 | ⩾4 | – | — | – |

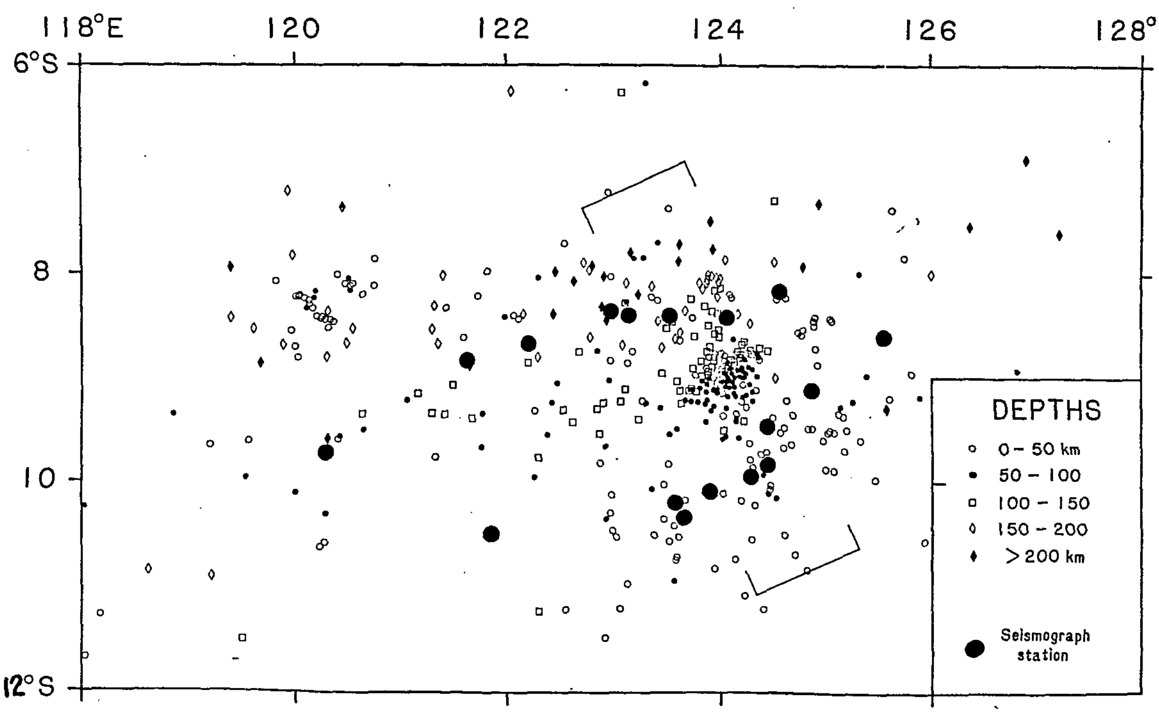


*Fig. 3.* Epicenter map for all earthquakes located by the temporary network. Brackets outline area of projection of Figure 5.

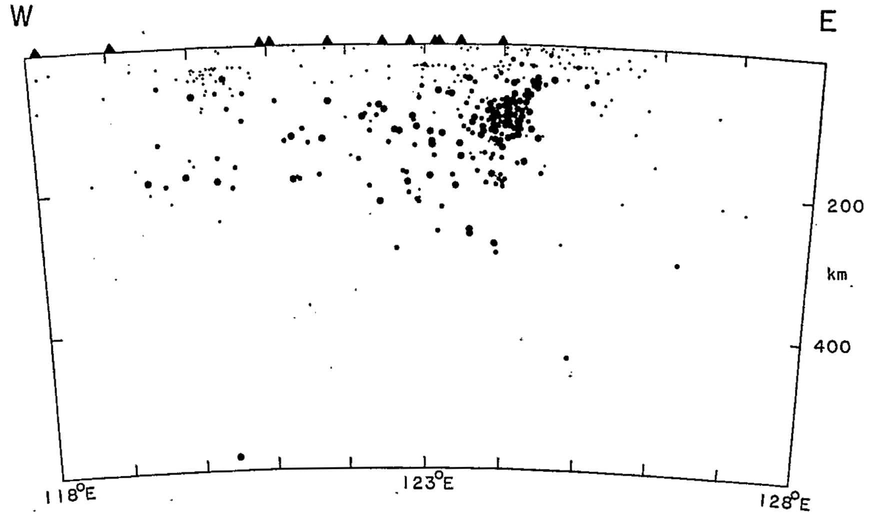


*Fig. 4.* Projection of all earthquake hypocenters onto an east–west vertical plane. Large dots represent class A events, intermediate size dots are class B, and small dots are class C. Triangles show active volcanoes at surface. No vertical exaggeration.

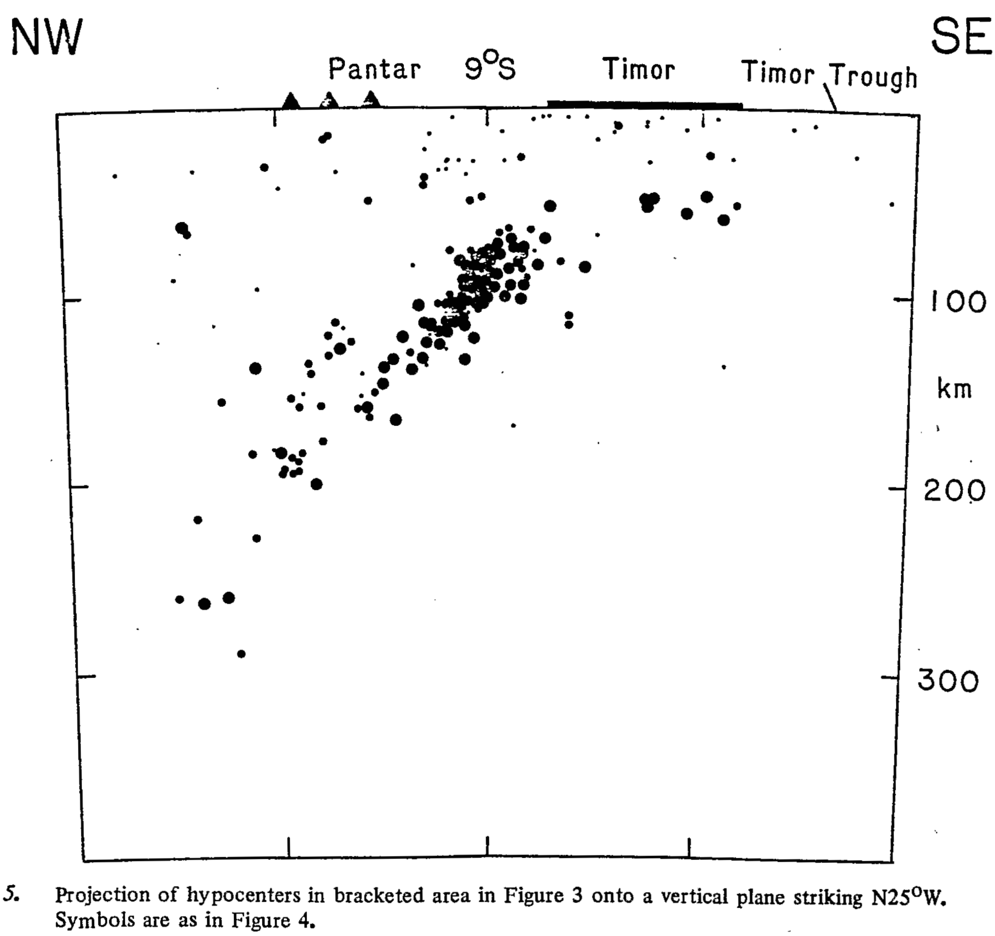


*Fig. 5.* Projection of hypocenters in bracketed area in Figure 3 onto a vertical plane striking N25°W. Symbols are as in Figure 4.

200 km depth and continuing more sparsely to 300 km. At shallower depths, a few better located events (class A) form a zone that appears to flatten out at about 50 km depth beneath Timor. These events do not project towards the Timor trough but rather occur in the lower crust or upper mantle beneath Timor since the crust of Timor is probably about 40 km thick (Chamalaun *et al.,* 1976).

One striking feature of the seismic zone between 100 and 200 km depth is the presence of two separate lineations about 30 km apart that converge at about 200 km depth. This feature of the seismic zone is not an artifact of the projection as the events in the upper zone are at the same longitude as those that form the lower zone. It is difficult to decide whether or not this truly constitutes a double seismic zone, as is observed beneath Japan (Hasegawa *et al.,* 1978), because the locations of most of the earthquakes in the upper zone are of class B, representing less well constrained locations.

The majority of earthquakes occurring at less than 50 km beneath Timor depth are classified as C due to the requirement that the nearest station be within one or two focal depths of the epicenter. The depths of these shallower events are in general not as well constrained as those of the deeper events. Nevertheless, we suggest that many of these earthquakes occurred within the crust for two reasons. First, stations operating on Timor recorded many events with S–P times of less than 5 s, implying a focal depth of less than 40 or 50 km. Secondly, seismograms of earthquakes that occurred near the stations on Timor often displayed a strong degree of ringing probably due to scattering and indicative of a source within the crust.

Figure 6 is a projection of all earthquakes shown in Figure 3 west of 123.3°E on to a north trending vertical plane. The better located events (A and B) outline a seismic zone that dips to the north to almost 300 km depth. This seismic zone projects upward towards the Java trench at 11°S and represents the subducted portion of the Indian Ocean plate. The scattering of hypocenters in this projection is probably due to the large width of the projection area.

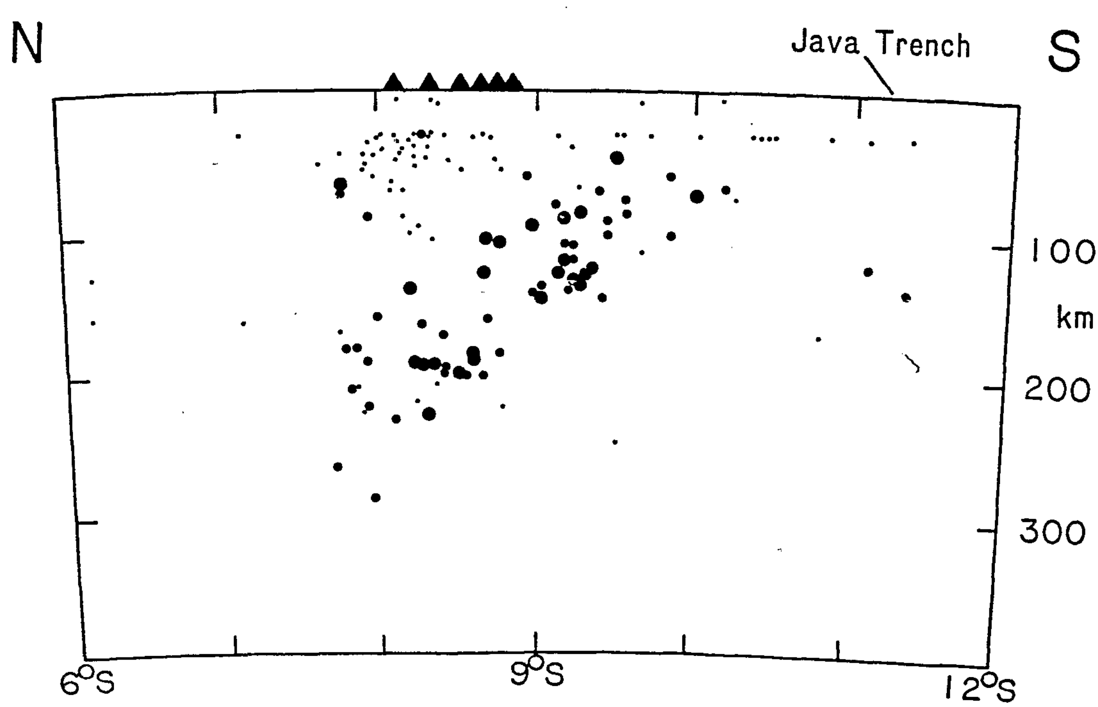


*Fig. 6.* Projection of all hypocenters between 118.75°E and 123.25°E onto a north-south striking vertical plane. Symbols are as in Figure 4.

A large number of shallow events occurred just south of 8°S (Figure 6). In map view (Figure 3), we see that most of these occurred beneath western Flores and are associated with the sequence on August 6 and 7. We infer that these events probably result from deformation of the island arc during collision because a preliminary fault plane solution for the main event of August 6 shows a strike-slip mechanism (from the National Earthquake Information Service).

## EVENTS OF MAGNITUDE 5.0 OR GREATER

During the survey period, seven earthquakes of magnitude 5.0 or greater (as reported in the Preliminary Determination of Epicenters Bulletin) occurred within the field area (Figure 1 and Table 3). The largest of these occurred north of western Flores at $20^h40^m$ UCT on August 6 and was of magnitude 5.9. This event was followed by a $m_b$ = 5.5 earthquake in the same region 5 minutes later. Both events were felt by members of the survey team in Ende and Maumere. Another, smaller ($m_b$ = 5.3) shock occurred in the same region on August 21 at $05^h06^m$. All of these events were shallow but the depths are poorly constrained by our data.

Two large events occurred within the seismic zone at 9°S and 124°E. These occurred at depths of 46 km (August 2, $10^h49^m$, $m_b$= 5.4) and 86 km (August 11, $10^h28^m$, $m_b$ = 5.5). We have no reports of either event being felt. One very shallow event of magnitude 5.0 occurred on August 9 at $03^h15^m$ beneath the central Savu Sea. Finally, a very deep shock (579 km) occurred north of western Flores on August 9 ($21^h09^m$, $m_b$ = 5.2).

## DISTRIBUTION OF S – P TIMES

The difference between the arrival times of the P and S wave at a seismograph station is a direct measure of the distance between the station and the hypocenter. By examining the frequency of occurrence of S – P times at a single station, we can often gain insights into the distribution of earthquakes not apparent from the pattern of locatable events. In Figure 7, S – P times are plotted against the number of events for many of the temporary stations.

The stations on Timor (Figure 7a) show a large number of S – P times of less than about 20 s and in the range 30 – 70 s. (The S – P times can be multiplied by 10 to make an approximate conversion to distance in kilometers). The presence of events with S – P times of less than 5 s (especially at Kefamenanu) indicate that the crust of Timor is involved in the deformation associated with the collision process.

The peaks of 14 s at Atambua, Soe, and Hadakewa, 10 s at Kefamenanu, and 13 s at Pantar, (Figure 7 b) are due to earthquakes from the intermediate depth seismic zone at 9°S and 124°E. Both Hadakewa and Pantar show peaks at 4 – 5 s indicating shallow earthquakes along the volcanic arc. The arc in this region is cut by numerous shallow faults (Silver *et al.*, 1983) which may be active but the earthquakes may also be due to volcanic activity. Ende and Maumere show strong peaks at 19 and 24 s, respectively; that are due to the swarm of activity north of western Flores.

The broad peak between 30 and 70 s at the Timor stations (Figure 7a) is conspicuously absent from the stations along the volcanic chain (Figure 7b).

Table 3. *Earthquakes of Magnitude 5.0 or Greater*

| Date 1982 | Origin Time Hr | Mn | s | Latitude °S | ' | Longitude °E | ' | Depth km | Magnitude |
|---|---|---|---|---|---|---|---|---|---|
| August 2 | 10 | 49 | 36.7 | 9 | 3.4 | 124 | 2.0 | 46 | 5.4 |
| 6 | 20 | 40 | 56.0 | 8 | 6.1 | 120 | 31.3 | 25 | 5.9 |
| 6 | 20 | 46 | 18.4 | 8 | 10.8 | 120 | 38.6 | 26 | 5.5 |
| 9 | 3 | 15 | 47.1 | 9 | 44.5 | 121 | 20.5 | 5 | 5.0 |
| 9 | 21 | 9 | 35.9 | 7 | 24.8 | 120 | 27.1 | 579 | 5.2 |
| 11 | 10 | 28 | 52.5 | 8 | 56.3 | 124 | 6.0 | 86 | 5.5 |
| 21 | 5 | 6 | 7.7 | 8 | 25.1 | 120 | 20.9 | 0 | 5.3 |

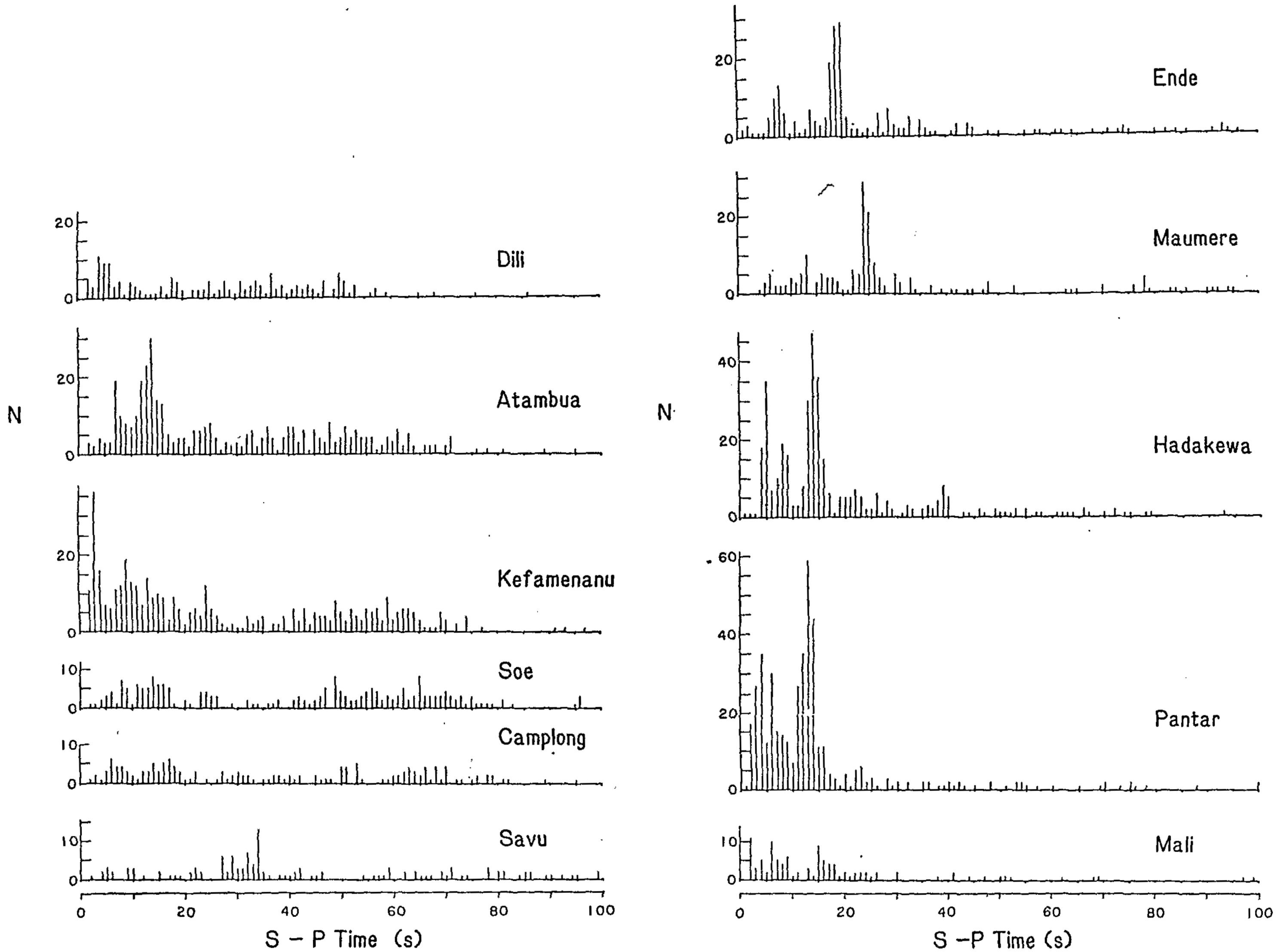


*Fig. 7.* Plot of S – P times (rounded to nearest second) against number of occurrences N.

It is likely that most of these earthquakes occurred near 7°S and 129°E within a zone of extreme activity along the eastern Banda Arc (Cardwell and Isacks, 1978). Apparently, shear waves from that area propagate poorly to stations on the volcanic arc but well enough to the southwest to be observed at the stations on Timor. This simple observation suggests preliminarily that the subducted slab north of the Timor trough is continuous beneath the eastern Banda Arc and north of Timor.

## SUMMARY

A 10 week microearthquake survey in Nusà Tenggara Timur during 1982 has provided a more detailed picture of the distribution of earthquakes in this tectonically active region. Many of the locatable earthquakes occurred in a dense seismic zone at intermediate depths beneath 9°S and 124°E. These earthquakes are part of a steeply north to northwest dipping seismic zone that projects upward toward Timor and probably represents subducted lithosphere of the Indian Ocean – Australian plate. East of this active region, where continental crust of Australia is involved in the subduction zone, earthquake activity is at relatively low levels and mostly at shallow depths. To the west, however, an intermediate depth seismic zone is observed to dip to the north from the Java trench to slightly less than 300 km depth. A swarm of earthquakes occurred near western Flores starting with a magnitude 5.9 event on August 6. Many of the shocks were felt in the Kabupaten Manggarai area and the main shock caused damage to several buildings.

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