بسم الله الرحمن الرحيم

# EARTHQUAKE MONITORING IN INDONESIA

**by**

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# FOREWORD

Earthquake is a natural disaster which confronts many countries. Earthquake studies are conducted in different parts of the world, especially in countries which experience frequent earthquakes.

Indonesia appears to be one of the most seismically active zones of the earth. About ten percent of the world earthquake events have occurred in this region and up to ten damaging earthquake events have been occurring annually in Indonesia causing loss of life and damage to property associated with structural failures of buildings, generation of tsunami, landslides, soil liquefaction and related ground failure.

One of the Science Programmes of the Islamic Educational, Scientific and Cultural Organization (ISESCO) deals with the preparation of studies directed towards prevention or mitigation of the effects of natural disasters. Accordingly, ISESCO invited the Geological Research and Development Centre (GRDC), Bandung, Republic of Indonesia to prepare a study on earthquake monitoring in Indonesia. Dr. Irwan Bahar, Director, GRDC and his colleagues have prepared the present study which describes, inter alia, the earthquake monitoring programme and the earthquake vulnerable areas in Indonesia.

We are grateful to the Geological Research and Development Centre, Bandung for preparing this study for ISESCO.

It is hoped that the present study will stimulate interest in the field of earthquake monitoring and contribute to the improvement of research in this field for the mitigation of the effects of earthquakes in various countries.

May Allah bless our efforts and protect us all from the calamities.

October 1997

Dr. Abdulaziz Othman Altwaijri
Director General,
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# I. INTRODUCTION

Indonesia is geographically located on longitude of 94°14' - 141° E and latitude of 06°08' N - 11°15' S. It is an archipelago consisting of more than 17,000 islands, among them are five big islands: Sumatera, Java, Kalimantan, Sulawesi, and Irian Jaya. The total land area is about 1,920,000 square kilometers and roughly one third of the total region is the ocean with 81,000 km long shoreline.

Approximately 60 percent of the land is covered by forest and about 40% is mountainous region; comprising a mountain range from the western coast of Sumatera passing through Java, Bali, curving north to Sulawesi island and continuing to the Philippines. Another mountainous belt lies in the central part of the Irian Jaya region. The climate is tropical with temperatures varying from 18° to 35° C. Snow is only found in some high mountains in Irian Jaya. Rainfall exceeds 7,000 millimeter per annum.

Sustainable development in Indonesia depends not only on economic growth but also on minimizing the effects of various catastrophes that may affect the country. Damaging earthquakes are a common occurrence in Indonesia, and available technologies need to be applied to minimize the effects of these catastrophes.

A number of measures are available to mitigate the effects of earthquakes. Among these are earthquake monitoring, disaster preparedness, land use planning, planning and relief, tsunami warning and building earthquake resistant structures.

Earthquake studies in Indonesia are mainly conducted in the densly populated regions and in the rapidly developing regions where the development of settlement and infrastructures is underway. The findings of different institutions are compiled to prepare earthquake microzonations of different areas. The objective is to provide relevant information and expertise to the government for earthquake disaster preparedness and mitigation.

The work presented here is an overview of the earthquake monitoring in Indonesia.

# II. GEODYNAMICS OF INDONESIAN REGION

## 1. TECTONICS OF INDONESIAN ARCHIPELAGO

Indonesia is tectonically located in the area of interaction of three megaplates: the Eurasian plate in the northern, Pacific plate in the eastern and Indo-Australian plate in the southern part (Figure 1).

In the Indonesia region, the pattern of plate boundaries ranges from the simple to exceedingly complex, and many concepts are suggested by their analysis (Hamilton, 1979). Fossil plate boundary systems can be identified, with widely varying level of confidence, from the geological record. Many of the tectonic elements are still separated by small ocean basins and so can be kept distinct from one another.

Nowhere in the world today three megaplates are in active motions and converging in a relatively small portion of the earth crust like in Indonesia.

The relative movements of these three plates define distinct subduction-collision system in Indonesia: the oblique subduction in Sumatera, frontal subduction in Java and the tripple junction in eastern Indonesia. The transition between the oblique and the frontal subduction system defines the opening around the Sunda Strait. The collision of the three major plates, which in turn created smaller plates, is responsible for the complex geological development of eastern Indonesia.

The Pacific plate which moves westernward with an average velocity of 6 cm per annum, the Indo-Australian plate that moves northernward at 4 cm per year, collide with Eurasian plate. The combination of the three plates interaction produces a complex tectonic and structural geology in the region, which in the eastern part of Indonesia is known to be more complex than in the western part, besides those also producing active volcanic belt which lies sub-parallel with main structural framework. This volcanic belt, extending from northern tip of Sumatera, Java, Nusatenggara, Maluku, North Sulawesi, covers a distance of about 7,000 kilometers.

The most important of structural geology are the active transcurrent faults in Indonesia. These are the Great Sumatera Fault which extends about 1,700 kilometers along the axis of Sumatera island, Palu-Koro Fault in Central Sulawesi and Sorong Fault which extends from Irian Jaya to Banggai-Sula islands in the east offshore Sulawesi island for about 2,000 kilometers length.

Even though the existence of the large transcurrent faults is already known, the parameters that relate to the earthquake monitoring and assessment are not yet sufficiently known. Improvement of technique, method and equipment facilities are urgently needed. A preliminary active fault measurement and study has already been done in Sumatera and Sulawesi. Meanwhile in Java the active structural geology appears to be a thrust fault system and some strike slip fault system.

## 2. GEODYNAMIC PROBLEMS IN INDONESIAN REGION

Due to its outstanding geodynamic location, Indonesia has been the object of various geological and geophysical investigations relating to geodynamical phenomena along the plate boundaries and other intraplate features.

### a. The geodynamics of the triple junction system

This is obvious in eastern Indonesia (the focal area of the triple junction system) where large -scale transcurrent fault associated with collision of some microplates, appears to be dominating (e.g. Sorong Fault Zone, Tarera-Aiduna Fault Zone, Pater Noster Fault Zone, Matano Fault Zone, Palu-Koro Fault Zone). Complication occurs in the central Sulawesi area where one can observe several features like the great translation movement of the Matano and Palu-Koro Fault Zones, the neogene magmatism in the western arc, the opening of Makasar Strait, the "stable" Kalimantan as part of the southeast Asian Continent, the subduction of the Celebes Sea. The nature (geometry, vertical and horizontal movements, timing and rate of movement, etc.) of these fault zones have to be clearly defined and, therefore, should be thoroughly studied (Figure 1).

### b. The geodynamics of oblique subduction system

The obliquity of the subduction resulted in the opening of the Andaman oceanic basin. The Andaman opening implies motion of about 450 km, while the opening in the Sunda Strait is only of 50 km. This suggests that the deformation is scattered all along the Sumatera margin. The seismically active fault segment around Tarutung - Panti area, the relatively low microseismicity along the other part of Sumatera Fault segments compared to those off the Sumatera mainland, and the extensional tectonics around the Sunda Strait, are some of the problems which need further investigation (Figure 2).

### c. Eustatic and isostatic movement

Recent crustal motions due to plate interaction, in some way, have created eustatic and isostatic movements in various lithospheric segments. The Indonesian region, which is built up by the relatively stable Sunda and Sahul continental masses and the intervening orogenic belt, must have shown quite a range of eustatic and isostatic movements. A precise kinematic pattern of the region for quantifying the present motions along the major active faults, uplifts, sea level changes, as well as to evaluate their consequences on the security and the evaluation of the marine and terrestrial environment is, therefore, needed.

# III. ACTIVE FAULTS OF THE INDONESIAN REGION

## 1. THE GREAT SUMATERAN FAULT ZONE

The great Sumateran dextral fault zone (synonyms: Semangko of Semangka Fault Zone) extends for the entire length of Sumatera. The dextral character of the fault zone is indicated by river and valley offsets and by the offset of granitic intrusion. Since the Late Miocene the dextral displacement has covered approximately 25 km. Some Jurassic outcrops suggest that the total displacement may have reached a distance of 180 km (Tjia et al., 1977).

The Sumatera fault zone consists of fifthteen fault segments (Figure 2). The majority of the segments are arranged dextrally en enchelon. It is found that the wider depressions, where normal faulting occurred, are located at their echelon junction. Kenematic considerations suggest that such junctions are subject to tension an account of dextral slip along the main fault.

The fifteen fault segments are as follows :

**a.** *Semangko Bay and the Semangko fault segment.* The southernmost part of the Sumatera fault zone begins with Teluk (Bay) Semangko which is a wedge-shaped depression narrowing northwestward from about 40 km to less than 20 km over a distance of 75 km. The bay's western scarp consists of step faults and is parallel to Sumatera's long axis. Microearthquake study in and around Semangko Bay (Kertapati, 1984) suggested that the seismic activity indicated a right-lateral slip-fault. The northernmost part of the Semangko fault segment stopped at the Liwa and Lake Ranau depressions. Damage by the Liwa earthquake of 1932 was concentrated in a narrow zone parallel to the long axis of Sumatera. Relative displacements of houses occurred in the NW-SE direction.

**b.** *Mekakau fault segment and Tanjungsakti graben.* This fault segment is arranged dextrally en echelon with respect to the former segment. The Tanjungsakti basin forms the northwest end of the segment. N-S and E-W topographic lineaments form parts of the boundaries of the basin.

**c.** *Keruh-Musi fault segment and Curup depression.* The Keruh-Musi fault segment is arranged sinistrally en echelon. The western fault scarp is well defined; its eastern scarp decreases from 100 m to less than 500 m towards the northwest. The Curup basin forms the north end of the segment. This basin is about 18 km wide.

**d.** *Ketaun-Seblat-Dikit fault segment and Muaraamen basin.* The Keruh-Musi and Ketaun-Seblat-Dikit fault segments are disposed dextrally en echelon. The Ketaun-Seblat-Dikit segment consists of generally parallel west and east walls and horsts. The basin lies between the slight, dextrally en echelon array of the Ketaun and Seblat valleys. It has been reported that the Tes earthquakes in 1952 resulted in relative lateral displacement of houses, respectively towards southwest for those on the west side and towards southeast for those on the east side. Relative lateral displacements in the villages of Turunlalang and Tes amounted to 0.5 metres; similar amounts of lateral displacement occurred at Kotadonok and Talangratu villages. Fissure eruptions along this fault segment produced the Plio-Pleistocene ignimbrite sheets that cover areas near Keban (Van Bemmelen, l949).

**e.** *Siulak fault segment and Kerinci graben*. This segment is disposed dextrally en echelon with respect to the former fault segment. The Siulak segment mainly consists of the 60 km long wedge-shaped graben in which the Siulak River flows. An E-W volcanic lineament that includes Gunungtujuh also occurs between the Siulak and Batang Saliti fault segments. Right- lateral displacement that accompanied an earthquake was recorded in the Kerinci Valley (earthquake occurred in l909).

**f.** *Batang Saliti or Batanghari fault segment and the Danau di Atas and Danau di Bawah depressions.* Between the Batang Saliti dan Solok-Singkarak fault segments are found the Danau di Atas and Danau di Bawah depressions. Posavec et al. (l973) suspect that the lineament represents an intrusive body below the volcanoes.

**g.** *Solok - Singkarak fault segment.* The Solok - Singkarak fault segment lies dextrally en echelon to the north of the Batang Saliti segment. The Solok - singkarak fault segment is of predominantly basinal character. Several east-west faults have also been detected; other faults are diagonal to the trend of the main fault zone. Kastowo (l973) indicates two other N-S striking normal faults a few kilometres to the west of Lake Singkarak. Best documented is the fault rupture associated with the l943 earthquake, which was described to us. Untung et al., l984) with remarkable recall by long-term residents in l3 selected localities along a 50 km-long segment of the fault near the town of Solok, between Danau (Lake) Singkarak and Danau di Atas. Since rupture clearly extended into Danau Singkarak on the northwest, and continued into an area of steep terrain and landsliding southeast of Danau di Atas, we estimate the total rupture length was at least 60 km. Ground cracking parallel to the fault was also described by local residents at least as far south as Surian. Local residents estimated strike-slip displacements in l943 of up to 5 m, but the largest horizontal displacement might be 2 to 3 m, as represented by an offset road near Saloyo.

**h.** *Sianok and Masang fault segments.* To the north the Solok-Singkarak fault segment is followed dextrally en echelon by the Sianok segment. The Sianok segment is a comparatively narrow graben-like structure. This segment is joined by another narrow structure, the Masang segment, that strikes north-south. Both narrow fault segments join without an intervening depression or volcanic range, as has been the case in all previous junctions. Tight- lateral displacement that accompanied an earthquake was recorded in Padangpanjang (earthquake of l926, reported by Visser & Akkersdijk, l927).

**i.** *Sumpur fault segment and Bangkuang Terpanggang depression.* Verstappen (l973) shows that at the approximate latitude of Lubuksikaping the Sumatera fault zone may consist of two major strands. One strand is called here the Sumpur fault and includes the town of Lubuk Sikaping, while the second parallel strand passed about l0 km farther to the west. The Sumpur graben joins the Masang fault segment without any appreciable en echelon arrangement. Towards the north, the Sumpur segment is diposed dextrally en echelon with respect to the Asik segment. The junction between the segments consists of more than 40 km long, 9 km wide, Bangkuang Terpanggang basin. Normal faulting with a minimum throw of 450 m is indicated by the west scarp. The east scarp is lower (l25 m above the floor of the basin) and has generally sinistral river off-sets amounting to between 70 and 200 m. Right lateral displacement that accompanied an earthquake was recorded in Lubuksikaping (earthquake in l977).

**j.** *Asik fault segment and Barumun plain, Batang Gadis fault segment and Panyabungan depression.* The Asik fault segment forms part of the eastern fault strand and is located dextrally en echelon with respect to the Sumpur segment. The western fault strand is formed by the upper Batang Gadis valley that, towards the north, is joined through the 35 km long and 8 km wide Panyabungan depression with the Angkola south segment. The scarps are l50 m (west) and 50 m (east) high. River valley off-sets are all sinistral, between 240 and 300 m on the west wall, and l60-200 m along the east wall.

**k.** *Ulu Aer fault segment and Lubukraya-Sibualbuali volcanic range; Angkola-south and Angkola-north fault segments and the Siabu depression.* The eastern fault strand continues as the Ulu Aer fault segment that is disposed dextrally en echelon to the Asik segment. The Ulu Aer segment cuts through accidented terrain and is confined to an extremely narrow strip. Dextral river offsets along this stretch are the rule. The 35° trending Lubukraya-Sibualbuali volcanic range forms a l5 km long positive lineament at the north end of the segment. Along the westen fault strand, the Angkola- south fault segment lies dextrally en echelon in the continuation of the Batang Gadis segment. Farther northwards, the Angkola- north fault segment also lies dextrally en echelon with respect to the Angkola-south segment. The two Angkola segments are joined structure, by the l7 km long 5.5 km wide Siabu depression which has north-south striking margins in addition to those striking parallel to the axis of Sumatera. The Angkola-north segment ends in the north against the earlier mentioned Lubukraya-Sibualbuali volcanic range.

**l.** *Batang Toru fault segment and Tarutung depression.* The Batang Toru fault segment lies sinistrally en echelon and dextrally en echelon to the north segments. The southern Batang Toru valley is narrow and well defined. The north end of the fault segment is formed by the Tarutung basin. Right-lateral displacement that accompanied earthquakes was recorded in the Tapanuli area (earthquake of l7 May, l982) and attained l.8 m to l.9 m in distance, and the Pahajae/Tarutung area (earthquakes of ll October, l94l; 25 July, l965, and 27 August, l984). Verstappen (l973) sees recent normal faulting in the straight alluvial/lacustrine terrace edge near Tarutung. North-south lineaments are again distinguishable along parts of the basinal boundaries.

**m.** *Lae Renum fault segment and Kutacane depression.* The Lae Renum fault segment continues as a presumably dextrally en echelon strand to the north of the Batang Toru segment. Northwest of the Tarutung valley, lineaments in the so-called

'Sumatera Trend' can be followed up to Dolok Sigotigoti. Beyond this hill, consistent dextral valley displacements of the order of 500 metres or less are shown by the upper tributaries of the Air Doras. With a few gaps of 5 kilometres or more, compatible valley lineaments connect with the extremely well-defined, narrow Lae Renun valley. The Batang Ahirta valley is one of the more distinct lineaments. Dextral river offsets are also evident along the east side of the narrow basin.

**n.** *Wai Ni Gumpang fault segment*. This fault segment lies dextrally en echelon in the continuation of the former segment. It begins as a narrow bundle of parallel drainage lines. Verstappen (l973) reports that solfataras occur along the road between Kutacane and Blangkajeren. Blangkajeren lies in a basin, 9 km wide, with parallel fault scarps as flanks.

**o.** *Krueng Aceh fault segment and Banda Aceh depression*. The Krueng Aceh fault segment begins near Pantelima and assumes the usual Sumatera trend. The segment lies dextrally en echelon with respect to the Wai Ni Gampang segment. The apparent l0 km offset is probably due to left slip along the Peusangan fault.

The Sumatera fault zone ends in the triangular alluvial plain of Banda Aceh (formerly known as Kutaraja); the base of the triangle faces north. A few of the important earthquakes are; in the Aceh area (l964) where there was displacement of 0.5 m; in the Tapanuli area in l982, l983 and in l984. The general dextral slip charater of the Sumatera fault zone is compatible with a regional compression that acts within the sector N 002 - 008 E (Tjia and Posavec, l972).

## 2. LEMBANG FAULT, JAVA

A 22 km long, northwards-facing scarp that strikes parallel to the long axis of Java and which outcrops amidst young volcanic deposits about l0 km north of Bandung has been designated as the Lembang fault. Twelve rivers and valleys that cross the fault from north to south indicate left-lateral displacements that range between 75 and 250 m, with an average displacement of l40 m.

Anthropological data show that faulting must have occurred between 3000 and 6000 years ago (Van Bemmelen, l949). The left-lateral slip component of the Lembang fault is compatible with a SSW - NNE regional compression.

## 3. CIMANDIRI FAULT, JAVA

Many destructive earthquakes have had their epicentres within a northeast striking zone that is located in the Cimandiri River valley with a normal fault zone that strikes ENE along the Cimandiri Valley. The downthrown block is to the south. The place the fault zone occupies is near the boundary between an area of tilting and warping (to the south and east) and a large area of folding (to the north and west).

Other faults have been mapped in the area. The Bency normal fault strikes ESE with the down-thrown side to the south due to the Sukabumi earthquake, l982 (Kertapati and Koesoemadinata, l982). Surface rupture following the main shock was also mapped by Kertapati and Koesoemadinata (1982). They found mostly strike-slip faulting striking perpendicular to the Cimandiri Valley.

## 4. CITANDUY VALLEY FAULT AND BANYUMAS FAULT

The Citanduy valley lies between two different morphotectonic complexes; the valley is actually a weak zone in a geological struture of a tectonic result. Sukamto and Simandjuntak (l983) have described the Citanduy valley as a fault zone. Near Banjarsari, in the Citanduy River, Pliocene strata have been slightly affected by the fault. Many destructive earthquakes have had epicentres within a northwest striking zone that is located between West and Central Java. Between l96l and August l97l, two shallow earthquakes originated in the fault zone. The analyses of the focal mechanism of microearthquakes in the Citanduy valley shows a reverse fault with a component of a horizontal faulting (Kertapati et al., l983). From gravity data of Java (density of measurement amounts to one station in every six square kilometres), the structure indicated by the Banyumas depression, or Citanduy valley, has been interpreted as representing normal faulting down-throwing to the east. A few of the important active faults in Java are: Bogotsari fault, Kemulan fault, Solo fault, Lawu and Cemorosewu fault. Numerous earthquake epicentres are located within these fault zones. A few of the important earthquakes are: in the Wonosobo area (l924), in the Semarang area (l865, l872, l959, l966, l968), in the Lawu volcano area (Des l979, l98l). In the Lasem area (l890, l958, l959 and l966) a microearthquake study of the Lasem fault shows reverse faulting.

## 5. PALU-KORO FAULT ZONE, SULAWESI

The Palu-Koro fault zone was formerly known as the Fossa Sarasina graben. It strikes south-southeast and stretches from Palu Bay towards SSE for 300 km on land, while it has a 400 km long submarine extension in the Gulf of Bone (Tjia and Zakaria, l974). Figure 3 shows fault system of Sulawesi Island.

The Palu Bay and Palu valley are bordered by step-fault topography, part of which consists of truncated alluvial fans, triangular to trapezoidal facetted scarps. Farther toward the SSE the fault is indicated by straight narrow valleys that are interrupted by small basins. Within this narrow portion are found abundant indictions of faulting: fissured rock, mylonite and striated fault planes (Brouwer, l947).

The Palu depression which includes Palu Bay and the Palu valley displays graben characteristics and step-faults have thrown reading 60 m or more. Along the narrower southern part of the segment, sinistral stream offsets in the range of l00 to 600 m are common features. Occasionally right-lateral displacements occur and have been interpreted as representing lag faults. Katili (l969) also noted consistent left-lateral stream offsets along the tributaries of the Koro River.

A kinematic analysis of fault motions of the Palu-Koro fault shows that the fracture system corresponded to horizontal regional compression that acted in an ESE - WNW direction.

Earthquake epicentres from within the fault zone prove the active nature of the fault zone. Three of the better known earthquakes occurred at Gimpu (l905) and at Kantewu (l934). McCaffrey et al. (l983) proposed that two microearthquakes were located in west-central Sulawesi where association with an active tectonic feature is unclear and that three occurred along the Palu fault - North Sulawesi trench system.

The lack of events recorded at Palu suggests that the Palu fault generates very little routine activity. Several large ($M > 7.0$) earthquakes have been centred on the Palu fault in the past 80 years, however, indicating its long-term importance in the tectonics of Sulawesi.

## 6. MATANO FAULT ZONE, SULAWESI

The Matano fault zone is a l70 km-long topographic lineament that extends between Losoni Bay and a point close to Lake Poso in Central Sulawesi. The fault zone strikes WNW, with five sinistrally en echelon segments along the fault zone. Lake Matano occupies a l5 km-long graben that is located at the junction of two en echelon segments. Lateral offsets of lighologic contacts are distinctly shown by the distribution of crystalline metamorphic rocks, Mesozoic sediments and ultrabasic rocks. Parallel to the fault zone, offsets amount to l9 or 20 km in the sinistral sense. Younger lateral shifts are represented by multiple sinistral stream displacements in the range of 200 to 600 m. The Matano fault zone may be the western end of a huge left-lateral shift. Within the Matano fault zone are located three shallow earthquake epicentres that occurred between l96l and August l97l.

Another of the important active faults in Sulawesi is the Gorontalo fault, as proposed earlier by Katili (l978). McCaffrey et al. (l983) reported that stations at Gorontalo and Luwuk show a broad range of S-P times, from 5 to 30 s. The scarcity of S-P times less than l05 at the Gorontalo station suggests that the Gorontalo fault is not a very active feature. Based on data from the Meteorology and Geophysics Agency, Jakarta, it is certain that within the Gorontalo Fault are located shallow earthquake epicentres.

The Sadang Fault: McCaffrey et al. (l983) reported that the Makale station recorded many local earthquakes with S-P intervals ranging from 5 to 7 s. All of these events occurred within about 50 km north of Makale. The region of intense activity north of Makale lies about halfway between the Palu and Sadang faults and is not easily interpreted. We have data which show that within the Sadang fault are located shallow earthquake epicentres.

## 7. THE CENTRAL STRUCTURAL VALLEY OF TIMOR

The so-called "central graben" of Timor extends for almost three quarters of its length along the axis of the island. The central valley reaches width of l5 km and its morphology agrees with its original designation. However, one central strand of the fault zone that is exposed where the Noil (River) Mina begins, at the confluence of Noil Besiam and Noil Leke, displays features of lateral displacement. The left-lateral slip along the Mina fault reflects the result of horizontal compression acting within the sector N l55°-245°E. On July l975, an earthquake of Magnitude 6.l and of 30 to 50 km focal depth caused damage to man-made structures and activated or developed new mud cones. Its epicentres was located on the island. Three or four shallow earthquake epicentres are depicted on Hamilton's map (l974).

## 8. REVERSE FAULT AT DOBO, ARU ISLAND GROUP

The Aru Islands are situated at the western edge of the Sahul platform. A terrace surface cut in reef limestone near the town of Dobo had been faulted along a plane striking N 355° E and dipping 80 degrees towards the east. Reverse faulting is indicated by the displacement and markings on the fault plane. A 2-metre wide mylonite zone of the same material occurs on the downthrown side. The entire fault plane is located within the intertidal zone, but the fault markings in the calcareous rock look fresh, suggesting the faulting to have taken place within the last 50 years (Tjia, l973).

## 9. IRIAN JAYA FAULT ZONE

The Irian fault zone comprises (a) the Matano fault belt in central Sulawesi, (b) the Sorong fault zone that consists of a submarine lineament in the Sula Islands and eastward until it appears on land in Salawati and then continues through Sorong and the northern Bird's Head toward Manokwari, (c) the north-northwest trending Ransiki fault zone, (d) the Japan fault zone across Cendrawasih Bay and the Waropen area as a row of mud volcanoes, (e) the Apauwar and Nimboran fault zones, to which probably also belongs the Tolateri-Gauttier fault zone that is parallel to the north coast and is located some kilometres farther to the south, and (f) distinct lineaments along the Bewani-Torricelli-Prince Alexander ranges in Australian New Guinea as far east as Wewak. Figure 4 shows fault system of Irian Jaya region.

## 10. THE SORONG FAULT ZONE

In the Bird's Head of West Irian the Sorong fault zone represents a distinct boundary between eugeosynclinal rocks to the north and miogeosynclinal rocks to the south. Within the fault zone mixtures of both rock groups are present. In the western and in the eastern Bird's Head the Sorong fault zone averages 4 to l0 km and sometimes exceeds l0 km in width and comprises both gigantic blocks and slabs of modest dimensions that form a tectonic breccia with confused internal structure, relatively underformed blocks lying embedded in a cataclastic to mylonitic groundmass. A granite outcrop near Sorong constitutes one tectonic unit of l0 km length. In the northeastern Bird's Head a series of parallel, east-west striking faults and a l0 km wide zone of ultramatic rock seem to define the fault zone.

Vertical and very considerable lateral displacements have occurred in the Sorong fracture zone. Both fault movements persisted at least until the Plio-Pleistocene; near Manokwari, Plio-Pleistocene Befoor strata have been slightly affected by the fault. The left-lateral slip, as envisaged by Visser and Hermes (l962), involves some 350 km since Miocene time.

The earthquake map covering the period l96l to August l97l (Hamilton, l974) records more than a score of epicentres of shallow earthquakes along the Irian fault in Irian Jaya. On l6 March l983, an earthquake of 30 to 60 km focal depth generated several sets of subparallel fracture zones following the Sorong fault zone.

## 11. THE YAPEN FAULT ZONE, IRIAN JAYA

Lineament in western Cendrawasih Bay comprises a submarine ridge, the straight north coast of Yapen Island, and a belt of mud volcanoes in the Waropen region (Visser and Hermes, l962). Yapen Island seems to represent a fractured fault block tilting to the south.

The Yapen fault zone consists of two main faults, the Jobi and the Randaway faults. The WNW - ESE trend, north of the Jobi, is composed of tectonic breccias or a chaotic sheared jumble of volcanics, intrusive and ultramatic rocks. The eastern extension of the fault is shown by a recent fault and mud volcanoes to the Memberamo River, and it runs into a zone of thrust faulting and diapiric intrusion further east.

A few of the important earthquakes in the vicinity of Waropen are: l94l, l9l6, l957 and in the Yapen one of l979.

## 12. THE RANSIKI FAULT ZONE

The Ransiki fault zone strikes 330°-335° and has been mapped along a distance of 43 km. Four major shear zones, aplite dikes, and fault-bounded gabbro-diorite bodies characterize the fault zone that has a total width of about l.5 kilometres. However, the Ransiki fault zone appears to have offset dextrally for a distance of 70 km two segments of the Irian fault belt, that is, the Sorong fault and the Yapen fault zones. On 29 June, l96l, an earthquake of magnitude 3 or 4, had its epicentre in the Ransiki valley, and the earthquake probably represented movement along the Ransiki fault zone.

## 13. OTHER ACTIVE FAULTS IN IRIAN JAYA

The Yakati-Yamur fault zone (Visser and Hermes, l962) occurs at the neck of the Bird's Head and runs almost north-south. The fault extends from the Yakati valley to Yamur Lake. Two shallow earthquake epicentres are located in this fault zone.

The Tarera-Aiduna fault zone trends east-west and separates predominantly pre-Tertiary sediments in the north from Tertiary deposits in the south. Immediately to the south of the fault left-lateral motion is implied by the disposition of WNW-striking fold axes in Tertiary sediments. Hamilton's map (l974) shows a close relation between the fault zone and about ten shallow earthquake epicentres.

# IV. SEISMICITY

Indonesia appears to be one of the very active seismicity regions in the world. Almost 10% of world earthquake events occurred in the region and up to ten damaging earthquake events have occurred here annually causing property damages and life loss associated with building structural failures, the generation of tsunami, landslides, soil liquefaction and related ground failure.

The seismic source of  the Indonesian region is spread out from the west of the Northern tip of Sumatera, Java, Bali, Nusatenggara, Maluku up to Irian Jaya region, sub parallel with main tectonic setting that controls structural geology in the region.

Damaging big earthquakes usually relate to the movement of an active fault and are located on land, with a shallow focus and a large magnitude. The buildings and facilities damaged are sometimes not only just the result of the ground motion but also caused by bad quality buildings that fail even with an earthquake of small magnitude.

## 1. EARTHQUAKE DISTRIBUTION

Based on the depth of epicenter (Figure 5), distributions of earthquake can be described as follows:

**a. Shallow depth earthquake (0-85 km)**

| | |
|---|---|
| **Sumatera** | Sumatera  The epicenters disseminated at the southeastern part of the island, in north Sumatera; shallow depth quakes found at the Tarutung and Toba regions, some qukaes also found at the south of the island. |
| **Java** | The shallow depth earthquake dominantly found at the west of the island  and in its southern offshore. |
| **Nusa Tenggara** | The epicenter is disseminated generally in the southern part of the isles and also at Sumba and Timor, some evidences are observed in the northern coast of Nusatenggara. |
| **Sulawesi** | The seismic activities are situated in the northern and in the central part of the isle, some are found in the southwestern part of the island. |
| **Maluku** | The seismic activity is situated at the Halmahera and Banda region. |
| **Irian Jaya** | In this region the shallow seismic activity can be obseved in the northern and in the eastern part of the region. |

**b. Intermediate depth earthquake (85-300 km)**

| | |
|---|---|
| **Sumatera** | Seismic activties are disseminated at the north and western part of the region, and more to the south Sumatera up to Sunda Strait. |
| **Java** | The epicenters are distributed in the west and central part of the isle. |
| **Nusa Tenggara** | Seismic activity is found at Sumba and Sumbawa regions. |
| **Maluku** | The seismic activities are distributed at the Banda and Halmahera regions. In Sulawesi intermediate focus seismicity found in the northern part of the island. |
| **Irian Jaya** | Intermediate focal depth seismics found in the central part of the island. |

**c. Deep focus earthquake (> 300 km)**

| | |
|---|---|
| **Sumatera** | The deep focus seismicity is found in the eastern part of the island. |
| **Java** | Generally the seismicities are distributed in the offshore of Java sea. |
| **Eastern Indonesia** | The seismic activity is found in the north of Timor and Banda Sea region. |

## 2. SEISMIC SOURCE ZONES IN INDONESIA

An attempt has been made to construct seismic source zones in Indonesia based primarily on seismicity. Distribution of earthquake epicentres has been throughly discussed by Ritsema (1954). Seismotectonic data have also been taken into account. The seismicity data alone may be insufficient for a rigorous and detailed analysis, and so the seismic source zones based on these data are liable to future modification.

**a. An Outline of the Seismic Source Zones**

**(1)** Divided into areas according to the maximum magnitude of the earthquakes, based on a compilation by Becca Carter Holdings, such as typical maximum. Furthermore the b-Value is based on the formula log N = a - bM.

**(2)** Divided into areas of deformation, based on the compilation of Becca Carter Holdings.

**(3)** Divided into areas according to maximum acceleration for a return period of 20 years, published by Becca Carter Holdings.

**(4)** Plate tectonics system in Indonesia.

**(5)** Distribution of shallow earthquake epicentres of magnitude above 6.0 for the period 1897-1995.

**(6)** Expression of earthquakes frequency square during a certain time inverval.

Indonesia can best be regarded as the place of interaction of three crustal plates, namely: (a) Indonesian-Australian plate, (b) Eurasian plate, (c) Pacific plate.

Most of earthquakes in Indonesia can be assigned to one of three vigorous asymmetrical systems that mark the contacts between the Eurasian, Indonesian-Australian and Pacific plates (Figure 1).

The first, the most significant of these systems, is the Sunda-Arc, which expresses the subduction of the Indonesian plate beneath the Sunda shelf, a stable southern prolongation of the Eurasian plate. This plate is bounded to the east by the second main system, the Philippines arc, a similar expression of the subduction of the Pacific plate.

The third system forms an active margin of the Australian continent and continues the line of the Sunda Arc to the east. This third system marks the subduction of the Pacific plate beneath the Indonesian one.

The three systems meet in the North Maluku region which in consequence is an area of high seismicity. So the northernmost region of Indonesia (Maluku Sea and surroundings) is probably one of the world's most vigorous areas of seismic activity. The intermediate earthquake activity in this area is very pronounced, skirting Minahasa and extending to the north via the Maluku Sea to the Philippines.

Earthquakes associated with the trenches of the island arc area, according to Isacks and Molnar (1971), are closely related to the underthrusting of the sea block beneath the landward block.

On land, shallow earthquakes occur along fault zones and folded zones. It could further be deduced that the remarkable shape of North Sulawesi and Halmahera and, in addition, the loop shape of the Banda arc are due to the combined results of the northward drift of the Indonesian-Australian plate (Australian continent) and the westward drift of the Pacific plate. It is a well known fact that earthquake epicentres may be associated with deep submarine troughs, which run parallel to the coast of the continent wherever the coast is lined by mountains.

Island arcs and active continental margins are typical of such subdudction zones. These are also characterized by deep-focus earthquakes. Many earthquakes, including the great ones for which the magnitude exceeds 7 or 8, occur in association with such a subduction of the oceanic plate. The down-going plate seems to reach a depth of 645 km. Many deep-focus earthquakes are located within the dipping plate.

Epicentres are sometimes distributed along a nearly straight line in highly seismic areas. Such lineations seem to lie closely correlated with active faults. Small stable units exist within the complex of active systems in East-Indonesia.

The Sunda arc is composed of the Sumatera segment, Java segment and Timor segment. The Sumatera segment is characterized by the presence of an outer island arc and the absence of deep quakes east of it. Java displays typical features, such as the occurrence of deep foci north of the island.

The interdeep area between the volcanic arc and the non-volcanic arc is generally subjected to a state of compression. The crust comes to a rupture probably between the continental and oceanic plates, when the compression exceeds a certain limit. The main quake is generally associated with a tsunami, causing serious loss to life and property in coastal villages. Numerous earthquakes occur in the interdeep area, just at the plate where, opposing a long deep ocean trough, there are great mountain ranges at a long distance back from the shore.

On land, shallow earthquakes occur along fault zones and folded zones, e.g. folded areas in Sunda arc, Irian Jaya and Sulawesi. Further fault zones can be mentioned as follows: Great Barisan fault, extending from Aceh to Lampung, runs parallel to the west coast of Sumatera; many small faultings in the other islands of the Sunda arc; Palu fault in Central Sulawesi and Gorontalo fault in the Minahasa; the Sorong fault runs along the north coast of Irian Jaya; further, the submarine faultings from Gulf of Tomini running to the Philippines via the Maluku Sea.

The Sorong fault in northern Irian Jaya is associated with the westward motion of the Pacific plate and marks the subduction of the Pacific plate beneath the Indonesian one. Back to the south is the folded area which runs from east to west approximately in between the north and south coast of the island. The seismic activity diminishes gradually southward.

Except for the small northern part, South Sulawesi has minor seismic activity. The subduction below Minahasa and the faulting in and around Minahasa and, further, the Palu fault in Central Sulawesi are responsible for the active seismicity of North and Central Sulawesi. This activity runs northward along the Sangihe ridge.

Kalimantan has been spared the experience of major earthquakes. However, this area has not been seismically inactive.

Indonesian region is divided into 6 seismic source zones (Figure 6) :

**a. Source Zone 1**

This zone comprises the northern part of Irian Jaya and the northern portion of Maluku, except the island of Halmahera. This zone forms an area of frequent earth deformation during the last 20,000 years and has experienced numerous shallow earthquakes.

The maximum magnitude in this area is of the order of 8.5 and its b-Value is 1.09. The earthquakes are concentrated west of the island of Halmahera and their frequency is 20.1 events per square degree for the period 1976-1983; the frequency of the earthquakes in the area surrounding Jayapura is 16.0 events per square degree, while in Sarmi and its surroundings it is 12.0 per square degree. The expected maximum acceleration in this zone is more than 0.69 g or, as intensity, more than X MMI.

**b. Source Zone 2**

This zone comprises (1) the coastal region of west Sumatera and south Java including the interdeep area; (2) the islands in the Timor segment (Nusatenggara Timur) and (3) Maluku, Minahasa and surroudnings and Fak-fak and surroudings.

**1.** The Coastal Region of west Sumatera and south Java. This areas include a small part of the west coast of Sumatera and the islands west of it, a small part of southern West Java and parts of the south of Central Java Sea and West Java Sea.

**2.** Nusatenggara Timur includes Sumba, the southern part of Timor and the small islands in the surrounding area.

**3.** Maluku includes Yamdena, Ceram, Buru, the eastern part of Sula, Obi, Halmahera, the southern part of Minahasa (North Sulawesi) and the islands in the Gulf of Tomini and finally Fak-fak in Irian Jaya and the areas east of it, extending from east to west. The seismicity of the zone can be summarized as below, based on the frequency of the events from the trenches up to the coast.

In the interdeep area numerous earthquakes have occurred from the trenches up to the coast. The frequency of the events in some places in the interdeep area is described below :

**a.** In the sea areas south of Bengkulu as many as 10.4 events per square degree during 1976-1983.

**b.** Off the south coast of Bantam as many as 6.4 events per square degree.

**c.** In the surroundings of Siberut as many as 4.9 events per square degree.

**d.** In the sea areas north of Yogyakarta as many as 4.7 events per square degree.

**e.** In areas southwest of Banda Aceh as many as 4.5 events per square degree.

The entire seismic source Zone 2 is located in an area of frequent earth deformation during the last 20,000 years. The maximum acceleration, as from the area south of Aceh to the west as far as the area south of Sukabumi to the east in seismic source Zone 2, does not exceed 0.69 g or, as intensity, IX MMI, while its expected maximum magnitude is 8.5. In the areas south of Preangan and south of Central Java the maximum acceleration does not exceed 0.33 g or, as intensity, IX MMI, while its expected maximum magnitude is of the order of 8.0.

In the Timor segment and Maluku areas the highest frequency (values of N) of felt earthquakes is found in Jamdena Island and surroundings, as many as 55.0 events per square degree during 1976-1983. Further, the frequency of the area west of this island and that east of Wetar is as high as 33.0 events per square degree. The frequency in the lesser Sunda Islands, comprising Bali, Lombok, Sumbawa, Sumba and Flores, is as high as 8.2 events per square degree, while in Timor and surroundings it is 2.0 events per square degree only. All the islands mentioned above are located in an area of frequent earth deformation during the last 20,000 years.

The expected maximum magnitude is of the order of 8.0 for Nusatenggara Barat while Java and Nusatenggara Timur have experienced earthquakes of 8.5 maximum magnitude. The expected maximum acceleration in Nusatenggara Timur does not exceed 0.69 g or, as intensity, X MMI.

Maluku, comprising Ceram and the surrounding sea area and also the western portion of Halmahera, is located in an area of frequent earth deformation during the last 20,000 years. The expected maximum magnitude in Central Maluku is of the order of 8.0. The highest b-Value is found in Central Maluku, and for areas in the Gulf of Tomini it is 0.90 while for Nusatenggara Timur it is 0.98.

The maximum acceleration in Central Maluku (Zone 2) does not exceed g or, as intensity, X MMI.  This figure can be used in Irian Jaya as from Fak-fak, Nabire and further eastward. The frequency of the felt earthquakes in Fak-fak, Nabire and further eastward cannot be compared with that in zone 1. Nonetheless this region is located in an area of frequent earth deformation during the last 20,000 years.

The Java trench running to the south of Zone 2 from west to east bends as from the south of Jamdena Island northward and comes to an end just at a point north of Ceram. Due to the subduction of the Indonesian-Australian plate beneath the Eurasian one, the earthquakes originate more deeply further to the north.

Earthquakes at a depth of 100 km are, therefore, observed along the west coast of Sumatera and the south coast of Java, while along the north coast of Java a depth of 300 km is observed and further in the Java Sea a depth of more than 300 km is detected.

Most of the damage in Sumatera, Java and Nusatenggara was caused by local shallow earthquakes and not by earthquakes originating along the trenches or in the interdeep over.  More significant are the N-S trending fractures in Nusatenggara Timur, as there the Indonesian plate (Oceanic plate) seems to be heavier than that east of it, e.g. the Australian plate.  It is thought that the Indonesian plate is descending more rapidly than the Australian plate.

**c.  Source Zone 3**

This zone consists of the western coastal region of Sumatera, the southern part of Java, Bali, Lombok, Sumbawa, the northern portion of Flores; from the Banda Sea up to the west coast of Central Sulawesi, the major portion of Minahasa (North Sulawesi) and the eastern part of the Sulawesi Sea area. The above mentioned area is located in a region of frequent deformation during the last 20,000 years, except for the Maluku area and Central Sulawesi, the area east of Poso and the Sulawesi Sea area.

The expected maximum acceleration in zone 3 does not exceed 0.33 g or, as intensity, IX MMI and that in the southern part of Central Sulawesi does not exceed 0.25 g or, as intensity, VII MMI.

The maximum acceleration in the sea area south of Ceram does not exceed g and is similar to that in zone 2. The expected maximum magnitude in Sumatera is of the order of 8.5, while the b-Value in that area is 0.95 ; Java has a maximum magnitude of 8.0  and b-Value of 1.09; Nusatenggara and Maluku have a maximum magnitude of 8.5 and b-Value of 1.14; Central Sulawesi has a maximum magnitude of 7.5.

In the east Sulawesi Sea more earthquakes have been experienced than in the west Sulawesi Sea, as the east Sulawesi Sea is closer to the area of deformation, being located west of Halmahera where numerous erathquakes have been detected.  The east boundaries of earth deformation and that of zone 3 in Sumatera coincide and it is the same for the boundaries north of zone 3 for Java and Nusatenggara, comprising the islands east of zone 4.

As the Zone 3 is not located in an area of earth deformation during the last 20,000 years, the seismic activity in Sumatera, Java and Nusatenggara seems relatively higher than in Zone 4.

The frequency in zone 3 is similar to that in Zone 2, except in Lampung which has a frequency of 1.5 events per square degree during 1976-1983. Zone 3 is also found in Irian Jaya extending along the folded zones including Jayawijaya, which is situated in an area of earth deformation. The expected maximum magnitude is of the order of 8.5. The frequency for the area around Mt. Mandala is 16.0 events per square degree for the period 1976-1983. The frequency of shallow earthquakes in zone 3 is relatively lower than in zone 2. The maximum acceleration in zone 3 of Irian Jaya does not exceed 0.33 g or, as intensity, IX MMI.

**d. Source Zone 4**

This zone comprises the middle of Sumatera from N to S, the northern portion of Java, including the southern part of the Java Sea area, the Flores Sea as far as the south of Sulawesi, a small portion of the Banda Sea, South Sulawesi, the Makassar Strait, the eastern coastal region of Kalimantan and the northern part of the Sulawesi Sea.

Zone 4 is also found in southern Irian Jaya forming a narrow belt that is bounded to the north by folding (Jayawijaya Mountain). The expected maximum acceleration in zone 4 is less than 0.25 g or, as intensity, VIII MMI. In general Zone 4 is located outside an area of earth deformation during the last 2,000 years except for South Sulawesi and the northern part of the Makasar Strait.

The frequency in zone 4 is similar to that in zone 3 except in Lampung and north Bantam which have a frequency as high as 1.5 events per square degree for the period 1976-1983. The frequency in the area north of East Java and Nusa Tenggara Barat reaches 2.9 events per square degree.

**e. Source Zone 5**

This zone comprises the eastern coastal region of Sumatera including the sea area east of it, a part of the Java Sea extending from west to east and central Kalimantan extending from south to north.Zone 5 is also found in a sea area east of SE Sulawesi and SW Irian Jaya, extending from east to west just to the north of Merauke.

The expected maximum acceleration in zone 5 does not exeed 0.20 g or, as intensity, VII MMI. The expected maximum magnitude in zone has occurred in Sumatera, namely magnitude 8.5, in the Java Sea magnitude 8.0, while in central Kalimantan, S. Sulawesi and SE Sulawesi it is magnitude 7.5; further, in the sea area east of SE Sulawesi it is magnitude 5.5 and in Irian Jaya 8.5.

Zone 5 is situated outside an area of earth deformation during the last 20,000 years and in this area earthquakes have occurred sparsely.

**f. Source Zone 6**

This zone is more or less stable, although this area has always experienced small events sparsely. Zone 6 comprises the sea area east of Sumatera China Sea) or the Sunda sheft, west Kalimantan and the Sahul sheft (Arafuru Sea) including the southernmost portion of Irian Jaya. This zone is located outside an area of earth deformation during the last years and has never experienced shallow earthquakes of magnitude greater than 6.0 during 1897-1984.

This means that this area has never suffered significant damage caused by earthquakes. The expected maximum acceleration in zone 6 does not exceed 0.13 g or, in intensity, VI MMI.

The seismic source areas are summarized below.

**1.** *Highly active areas*. Shocks of magnitude 8 are known. Shocks of magnitude 7 or more are frequent. e.g. Philippines trench, Halmahera arc, northern coastal region of Irian Jaya.

**2.** *Active areas. Shocks of magnitude 8 could occur*. Shocks of magnitude 7 or more are frequent. e.g. Interdeep area off the west coast of Sumatera and off the south coast of Java; further, the small Sunda Islands east of Java, Timor segment, East Banda Sea, Buru and Ceram arc, folded zones of Irian Jaya and the Minahasa Peninsula.

**3.** *Folded and fractured zones*. Shocks of magnitude 7 and less are frequent, e.g. west coast regions of Sumatera, southern coastal regions of Java, the lesser Sunda Islands east of Java, Buru, northern part of central Sulawesi and central Irian Jaya.

**4.** *Folded zones with or without fracture zones*. Shocks of magnitude 7 or less have occured. e.g. Sumatera, northern part of Java, eastern and northern Kalimantan, Sula, South Sulawesi and central Irian Jaya.

**5.** *Areas where infrequent small earthquakes have been reported.* Eastern coastal region of Sumatera, Central Kalimantan, western Banda Sea, southern margin of the Sunda Shelf, southern part of Irian Jaya.

**6.** *Stable areas with no record of earthquakes*. Southernmost region of Irian Jaya, Arafura Sea (Sahul shelf) Sunda sheft except Kalimantan.

The earthquake source zones in Indonesia are bounded by latitudes 10°N to 15°S and longitudes 90°E to 145°E. These 6 seismic source zones range from Zone 1 which is the most seismicallly active up to Zone 6 which can be described as a stable one. The above-mentioned zones include also a part of Malaysia and Brunei Darussalam, plus a portion of the Philippines and Papua New Guinea.

The boundaries of the above-mentioned zones are nearly similar to those of the seismic zones for building construction. However, in the light of the results revealed by recent seismic and tectonic data, some modification is necessary.

Modification has been taking place in the interdeep area south of Java, in the sea area west of Sumba, in the sea area south of Ceram, in the northern part of South Sulawesi and in the northernmost part of Sulawesi.

The damaging earthquakes for the period 1921-1995 show that no disasters (damage by earthquakes) have occurred in Zone 5 and Zone 6 but only in Zones 1 to 4.

## 3. DESTRUCTIVE EARTHQUAKES DURING 1821-1983

### a. Zone 1

| Event | Felt | I max |
|---|---|---|
| Origin Time 1845 Feb 08 | **Menado** : North Sulawesi - A strong earthquake was felt in north Sulawesi and caused the collapse of brick buildings and houses at Menado, Tikala, Tomohon, Tonsarongsong, Tondano and Tanawanko. | MMI VIII-IX |
| Origin Time 1855 Jul 14 | **Ternate** : Maluku - A strong earthquake occurred. Severe damage to buildings; one house collapse and 34 people were killed. | MMI VIII-IX |
| Origin Time 1858 Feb 27 | **Ternate**: Maluku - A rather hard shock was felt and caused damage to walls. | MMI VI |
| Origin Time 1858 Jun 04 | **Ternate** : Maluku - Rather strong earthquake was felt, causing damage to some buildings and houses. | MMI VI |
| Origin Time 1858 Dec 13 | **Tondano** : North Sulawesi - A moderate earthquake caused sheds to fall. On Ternate, Tidore, Halmahera, Saingihe, Talaud and Banggai islands a tsunami was observed. | MMI VII |
| Origin Time 1859 Oct 08 | **Halmahera Island** : Maluku - At Halmahera a great number of cottages tumbled down. | MMI VI |
| Origin Time 1864 May 23 | **Arfak** : Irian Jaya - The destructive earthquake caused houses on Mount Arfak to be set ablaze and some houses were buried. 250 people killed. | MMI VI-VII |
| Origin Time 1867 Nov 03 | **Ternate** : Maluku - A moderate shock caused fissures in the walls of numerous houses. | MMI VI |
| Origin Time 1914 May 26 | **Japen Island** : Irian Jaya - All brick buildings collapsed on Japen Island. Ansus and Pom were affected by a tsunami. A few people lost their lives. | MMI IX |
| Origin Time 1919 Nov 21 | **North Irian Jaya** : Some damages were caused by a strong quake in the eastern part of north Irian Jaya. A few houses collapsed. Earth fissures developed in the ground and walls were disturbed. | MMI VIII |
| Origin Time 1921 Oct 10 | **Sentani** : Irian Jaya - A major earthquake was felt as far as Dobo, but was destructive around Lake Sentani in southeast Irian Jaya. Ground-slides, boulders and a large mass of limestone dammed up a branch of the river temporarily in the village of Doormantop. | MMI VII |

| | | |
|---|---|---|
| Origin Time 1932 May 14 Epicentre 0.5° N-126.0° E | **Tondano** : North Sulawesi - The strong earthquake was felt as far north as Mindanao. The major destruction took place at Kakas, south of Lake Tondano; 592 houses collapsed, 115 people sustained injuries and the death of six people was reported. Damage was also done at Langowan, Poso, Tondano, Waluyama, Rembohan, Koya and Lekupang.<br><br>Ternate in north Maluku suffered minor damage. On the coast between Amurang and Tompoan vertical gaping cracks developed in the beach sands and the seaside of the cracks sagged. | MMI VII |
| Origin Time 1936 Apr 01 Epicentre 3.6° N-126.7° E | **Sangir** : North Sulawesi - The quake seemed to be followed by numerous aftershocks. Destructive in the Sangir-Talaud Islands. Approximately 127 houses collapsed. Cracks in walls at Lerung. | MMI VIII-IX |
| Origin Time 1971 Jan 10, 07h 14m 3.7s UTC Epicentre 02.1° S - 140.1 ° E<br>Magnitude: 7.3<br>Depth: normal | **Sentani** : Irian Jaya - The quake was felt in most places in northern Irian Jaya and rocked Jayapura and Sentani. In Jayapura cracks developed in walls of brick buildings and ten wooden buildings on pillars floating on water collapsed completely.<br><br>In Sentani, 40 km away from Jayapura, a church was cracked and at 10 km further inland about 14 wooden houses on pillars toppled.<br><br>In Genyem, about 40 km away from Sentani, earth-slumps and fissures which erupted and the sand were observed. A sound was heard like gun fire. This area is sparsely inhabited and the sketehy information is due to difficult communications. | MMI VI-VII |
| Origin Time 1974 Feb 27, 00h 21m 57.7s UTC<br>Epicentre 2.7°N-125° E<br>Magnitude: 5.2<br>Depth: normal | **Siau Island** : North Sulawesi - The quake was followed by an aftershock on March 02. A roaring sound was heard, indicating that the quake was shallow.<br><br>On March 13, 1974 occurred a shallow earthquake again off the west coast of Siau Island. The shock caused people to panic; and due to the continuous strong shocks and the loose formation of the soil in that area, it caused ground- slides, ground cracks and damage to buildings. | MMI V |
| Origin Time 1976 Jun 25 19h 18m 29.0s UTC Epicentre 3.2° S -142.8° E<br>Magnitude 6.8 | **Jayapura** : The shock felt by many people but no damage was reported. According to the newspaper report the earthquake caused a landslide and ground cracks in the hinterland of Irian Jaya. | MMI IV |

| | | |
|---|---|---|
| Origin Time 1979 Jul 23 05h 52m 53.0s UTC Epicentre 2.5 º S-140.4º E Magnitude: 5.7 Depth: normal | **Sentani, Jayapura** : Irian Jaya - The shocks damage to buildings and houses in Sentani. | MMI VII |
| Origin Time 1979 Sept 12 05h 17m 52.4s UTC; Epicentre 1.8º S Magnitude:6.4 Depth: 50 km | **Japen-Serui**: Irian Jaya - This earthquake killed 2 people and injured 5 people slightly in Japen and Jobi villages. Many houses, buildings, school buildings and clinics collapsed or were seriously damaged. The villages that experienced damage are Ansus, Papuma, Serui, Ariepie, Aromarea, Sarawandori, Serui Laut, Kabuaena, Borai, Menawi, Kointunai, Dawai, Randawaya and Warironi. All the above- mentioned are located in the Japen District. | MMI VIII |
| Origin Time 1980 Feb 22 03h 51m 46.0s UTC Epicentre 1.5º N- 124.65º E Magnitude: 5.5 Depth: normal | **Manado** : North Sulawesi - In Manado cracks developed in some buildings and houses. No one reported killed or injured. | MMI VI |
| Origin Time 1983 Oct 22 21h 48m 44.4s UTC Epicentre 4.0º N-126.6º E Magnitude: 4.9 Depth: 118 km | **Sangihe-Talaud** : North Sulawesi - In the Sangihe-Talaud Islands cracks developed in the walls of buildings. No loss of life was reported. | MMI |

**b. Zone 2**

| Event | Felt | I max |
|---|---|---|
| Origin Time 1830 Mar 28; 01h 00m 00s UTC | **Ambon** : Maluku - Earthquake occurred and caused damage to buildings. | MMI VII-VI |
| Origin Time 1830 Nov 01 | **Ambon** : Maluku - A large earthquake occurred and caused some buildings to collapse; 60 people injured; landslides in the hilly areas were observed. | MMI VII-IX |
| Origin Time 1837 Jan 21 | **Maluku** : Earthquake felt at Saparua, Haruku and on Nusalaut Island ; caused damage to buildings and houses. | MMI VII-VIII |
| Origin Time 1841 Dec 16 | **Ambon** : A moderate earthquake occurred at Ambon. The earthquake was accompanied by a tsunami at Galaga Bay and Buru Island. The tsunami caused damage to some boats. | MMI VII-VIII |
| Origin Time 1843 Jan 05 | **Gunung Sitoli and Baras**: Nias Island - A strong earthquake struck Gunung Sitoli and Baras. The shocks were followed by a tsunami, causing damage to some boats. Ground-slump was observed too. | MMI VII-VIII |
| Origin Time 1858 Nov 09 | **Ambon** : Some buildings suffered damage by an earthquake. | MMI VI |
| Origin Time 1871 Aug 18 | **Bengkulu** : Sumatera - The quakes caused some houses to tumble down in Bengkulu and Tebingtinggi. | MMI VI-VII |
| Origin Time 1876 May 28 | **Kajeli** : Ceram - A few houses suffered damage and a mosque tumbled down at Kajeli-Ceram Island - Maluku. | MMI VII |
| Origin Time 1896 Apr 18 | **Timor Island** : The quake was also felt at Alor Island; 250 people killed and most of the settlement damaged. | MMI VII-VIII |
| Origin Time 1898 Jan 17 | **Ambon** : Maluku - Many houses were destroyed by this quake. | MMI VII |
| Origin Time 1902 Jun 27 | **Lais** : Bengkulu - Fall of plaster and cracks developed in walls. | MMI VI |
| Origin Time 1903 Feb 27 | **Banten** : West Java - This quake felt over Banten; small cracks developed in walls. | MMI VI |
| Origin Time 1908 Mar 24 | **Atapupu** : Timor Island - The quake strongly felt at Atapupu in Northeast Timor. Cracks developed in the wall of a fortress; a part of the wall fell. Damage to buildings also occurred in the Chinese blocks. Cracks developed in the beach sands about 25 m long. | MMI VII |

| | | |
|---|---|---|
| Origin Time 1920 May 10 | **Ambon** : Maluku - Cracks in walls reported at Ambon, Saumlaki and Banda. The quake itself had its origin about 1120 km south of Banda and Irian Jaya. | MMI VI |
| Origin Time 1923 May 12 Epicentre 7.3$^{o}$S-105.8$^{o}$E | **Banten** : West Java - The shock was felt over West Java and South Sumatera as far as Krue. Damage occurred at several places; at Pelabuhanratu a water tower was thrown down. | MMI VII |
| Origin Time 1925 Jul 24 | **Bacan Island** : Maluku - Exact origin unknown. Strongly felt at Labuban (Bacan Island), accompanied by a roaring sound; cupboard overturned, a pendulum clock fell. | MMI VII |
| Origin time 1931 Sept 25 | **South Sumatera** : Felt over South Sumatera and west Java and as far west as Padang. Foundations of most buildings subsided. Difficult to walk as a result of the earthquake. In Kalimantan a rumbling sound was heard. | MMI VII-VIII |
| Origin Time 1932 Sept 09 Epicentre 3.5$^{o}$S-128.3$^{o}$E | **Seram** : Molluca - The origin seemed to be in Tolehu Bay. A few old buildings collapsed at Wae and Tolehu. Ground-slumps and ground-slides were also reported. | MMI VII |
| Origin Time 1936 Aug 23 Epicentre 6.1oN-94.7oE | **Banda Aceh** : The quake was strongly felt at Banda Aceh, Lhok Sukon, Lhokseumawe and was followed by a number of aftershocks. Caused damage to buildings. As a result of the shocks 9 people said to have perished, 20 people were badly injured. | MMI VII-VIII |
| Origin Time 1938 May 20 Epicentre 0.7$^{o}$S-120.3$^{o}$E | **Tomini Gulf** : Central Sulawesi - The tremor was felt as far east as Kalimantan and as far north as Gorontalo (Minahasa). The shock was associated with a tsunami which swept the sea, causing serious loss of life and property; 942 houses collapsed and a few persons were drowned. | MMI VIII-IX |
| Origin Time 1938 Aug 18 Epicentre 3.8$^{o}$S-102.8$^{o}$E | **Bengkulu** : Sumatera - The shock was felt over West Sumatera, Palembang, Bengkulu and on the Mentawai Island. Fall of plaster and cracks in walls were reported at some places in Bengkulu. | MMI VII |
| Origin Time 1938 Oct 20 Epicentre 9. 2$^{o}$S-123.2$^{o}$E | **Flores** : Walls were badly cracked in Flores. Ground-slides at Larantuka. The quake seemed to have aftershocks. | MMI VII |
| Origin Time 1939 Dec 22 Epicentre 0.0$^{o}$S-123.0$^{o}$E | **Central Sulawesi** : This major earthquake was felt over north and central Sulawesi, East Kalimantan and as far north as the Sulu Islands. Cracks developed in walls at Gorontalo and Langonan; cupboards overturned and a few people were injured. Houses collapsed at Kalo, Luwuk, Labuba and on the Sula Islands. At Mandar and Meulaboh in central Sulawesi houses were shaken. | MMI VIII |

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| Origin Time 1941 Oct 11 Epicentre 0.6ºN-97.6ºE | **Tapanuli** : North Sumatera - Strongly felt over Tapanuli; slight damage occurred at Sibolga. | MMI VII |
| Origin Time 1941 Nov 09 Epicentre 1.4ºS-121.1ºE | **Gorontalo** : North Sulawesi - Brickstone buildings collapsed at Gorontalo, Paleleh and Cibawa. Ground-slumps and land-slides in the hills were reported. | MMI VIII |
| Origin Time 1960 Apr 29 09h 16m 20s UTC Epicentre 0.5ºS-121.5ºE | **Una-Una** : Central Sulawesi - Felt over North and Central Sulawesi. Destructive on the Una-Una Island. No lives were lost. | MMI VII-VIII |
| Origin Time 1961 Mar 16, 01h 18m 21s UTC Epicentre 8.1ºS-122.3ºE | **Flores** : East Nusatenggara - Damage in most villages in Central Flores; one person killed. | MMI VII-VIII |
| Origin Time 1964 Apr 02, 01h 11m 55s UTC Epicentre 5.9ºN-95.7ºE Magnitude: 5.2 Depth: 132 km | **Banda Aceh** : The earthquake was the strongest shock ever recorded in this region since that of August 23, 1936 which caused considerable damage to buildings.<br><br>The quake was most strongly felt at Banda Aceh where the intensity was high (VII MMI). About 30-40% of the brick buildings sustained damage. The village worst hit was Krueng Raya. | MMI VII |
| Origin Time 1967 Apr 12, 04h 51.2s UTC Epicentre 5.3ºN-97.3ºE Magnitude: 6.1 Depth: 55 km | **Aceh** : North Sumatera - The earthquake was felt mainly over the eastern coastal areas of Aceh, being located on alluvial deposits and to the south as far as Kisaran. Farther inland the shock was felt in Takengeun, situated in the mountainous region.<br><br>No report was received from places on the west coast of Aceh. The maximum intensity, about midway between Lhokseumawe and Sigli, probably did not exceed VIII MII. The places worst hit were Jeunieb, Pendada and Jeumpa Bireun.<br><br>Damage to buildings of 5 mosques, 59 brick and wooden houses which were used for religious purposes, 11 school buildings, 5 bridges and about 2000 brick and wooden dwellings. Furthermore, earth-slump, rock-slides, cracks and fissures were observed over a wide area; mud and sand erupted from fissures in soft, water-saturated deposits at some places.<br><br>In Sigli the quake was followed by an enormous tsunami, Eastern Aceh is a region of only moderate earthquake activity as compared, for example, with the west coast of Sumatera. | MMI VII |

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| Origin Time 1973 Nov 26 08h 51m 12.8s UTC Epicentre 6.8°S-106.6°E<br>Magnitude: 4.9<br>Depth: 62 km | **Pelabuhanratu**: West Java - In Pelabuhanratu the quake was felt as Intensity III-IV MMI. At Citarik and Cidadap villages, where the intensity was highest, the only known structural damage was slight cracks produced in the walls of old brick buildings and falling of plaster. Ground cracks and ground-slides were observed. | MMI V |
| Origin Time 1976 Jun 20 20h 56m 31.7s UTC Epicentre 3.2° N- 96.3° E<br>Magnitude: 6.1<br>Depth: 33 km | **Kotacane** : Aceh - Cracks occurred in the walls of the local government office building. Sibolga: Cracks in walls of the power house building at Pinangsore Airport. The earthquake was also felt by many people in Banda Aceh and Medan, but no damage was reported. | MMI VII |
| Origin Time 1977 Aug 19 19h 06m 08s UTC Epicentre 11.1°S-118.5°E<br>Magnitude: 7.0<br>Depth: 33 km | **Sumbawa**: East Nusatenggara - Quake and its epicentre was far from the land but, due to the tsunami which accompanied it, most of the southern part of the sea coast of Bali, Lombok, Sumbawa and Sumba was damaged. In Kuta, Bali one person killed and 5 houses collapsed, 26 boats damaged or missing. In Lombok 20 persons killed, 115 houses damaged, 132 boats missing or damaged.<br><br>In Sumbawa 81 people killed, 53 people missing, more than 1000 people lost their property; 63 houses, one school building, one mosque collapsed and the others were cracked. The quake also caused damage to some office buildings and school buildings and a mosque and market in Sumbawa and Bima. In the whole of Nusatenggara Island the quake resulted in 107 people killed, 54 people missing, 440 houses damaged/ collapsed, 467 boats missing or damaged, 5 shool buildings collapsed and 3 teachers' houses damaged. | MMI VIII |
| Origin Time 1979 Dec 15, 00h 02m 37s UTC Epicentre 3.5°S- 102.4°E<br>Magnitude: 6.6<br>Depth: 25 k m | **Bengkulu** : Sumatera - The quake caused damage in Kepahiang and Curup. No-one killed or injured by this quake, but many houses and buildings seriously damaged.<br><br>In Kepahiang, more than 550 houses seriously damaged and in the Rejanglebong area around 630 houses also seriously damaged; many others cracked on walls. Ground-slides and cracks were observed. Near Bengkulu, many houses were shifted from their foundations and water pipes were broken. | MMI VII-VIII |
| Origin Time 1980 Aug 17; 09h 01m 58.0s UTC Epicentre 3.7°S-128.5°E<br>Magnitude: 5.4<br>Depth: normal | **Ambon**: Maluku - Cracks in walls developed in some houses in the city of Ambon. No more damage was reported. | MMI V |

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| Origin Time 1982 Aug 06; 20h 40m 52.5s UTC Epicentre 0.35ºS-120.35ºE Magnitude: 5.6 Depth: 18 km | **Ruteng**: Flores Island - In Ruteng the quake was strong enough to make people panic and run out from their houses. No building or houses collapsed, but one hospital, one school building and one government office building and some houses were seriously damaged, and a microwave station building was slightly damaged. In Pagal, north of Ruteng, 2 school buildings, 1 church and 2 clinics were slightly damaged, cracks developed in walls and plaster fell. Cracks in the ground were observed. | MMI VI-VII |
| Origin Time 1982 Aug 23 16h 46m 34.7s UTC Epicentre 0.06ºN-121.20ºE Magnitude: 4.7 Depth: 5 km | **Una-una**: Central Sulawesi - A small island in Central Sulawesi province was hit by a moderate earthquake. The walls of several houses fell. Cracks developed in walls and plaster fell. No death or injuries were reported. | MMI VII |
| Origin Time 1982 Dec 25 12h 28m 2.7s UTC Epicentre 8.4ºS-123.04ºE Magnitude: 5.1 Depth: normal | **Larantuka**: Flores Island - The quake caused serious damage in Larantuka, Solor and on Adonara Island in East Nusatenggara Province.Hundreds of houses collapsed and thousands were slightly damaged, 13 people were killed, 17 injured and more than 400 slightly injured. | MMI VII-VIII |
| Origin Time 1983 Mar 12 00h 53m 36.0s UTC Epicentre 4.4ºS-128.05ºE Magnitude: 5.8 Depth: 25 km | **Ambon**: Maluku - The shock caused slight damage on Ambon. The quake was accompanied by a tsunami along the coast of Ambon. | MMI VI |
| Origin Time 1983 Apr 04 02h 51m 13.9s UTC Epicentre 5.8º S-93.27ºE Magnitude: 6.6 Depth: 51 km | **Banda Aceh**: North Sumatera - The quake caused both serious and slight damage at Banda Aceh. The walls of school buildings collapsed and window panes were broken. Some of the government buildings, for example the treasury buildings, TV station building, 1 room of the university building and the telephone office building, were damaged. In Meulaboh, on the west coast of Aceh, one building was slanted. | MMI VI |
| Origin Time 1983 Oct 31; 03h 37m 54.5s UTC Epicentre 9.55ºS - 119.09ºE Magnitude: 6.5 Depth: 179 km | **Waingapu**: Sumba - Nusatenggara - some houses around Mauhau Airport in Waingapu had cracks in their walls. The quake was felt in Ujungpandang and Denpasar, Bali. | MMI V |

## c. Zone 3

| Event | Felt | I max |
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| Origin Time 1828 Dec 29 | **Bulukumba**: In South Sulawesi a destructive earthquake occurred and caused severe damage to buildings; hundreds of people were killed. | MMI VIII-IX |
| Origin Time l833 Nov 24 | **Bengkulu**: Sumatera - a severe earthquake occurred and caused some buildings to collapse or be damaged. A tsunami was observed. No further information. | MMI VIII-IX |
| Origin Time l834 Oct l0 | **Bogor and Cianjur:** West Java - a violent shock occurred; the earthquake caused severe damage to buildings, some of which collapsed, and cracks in the road between Bogor and Cianjur. No deaths or injuries were reported. | MMI VIII-IX |
| Origin Time l835 Aug 26 | **Padang**: West Sumatera - the earthquake struck Padang and caused slight damage to buildings and cracks in walls. | MMI VII-VIII |
| Origin Time l837 Nov 28 | **Bima**: Sumbawa - a strong earthquake occurred, caused heavy damage to buildings, some of which collapsed. | MMI VIII-IX |
| Origin Time l840 Jan 04 | **Purworejo**: Central Java - a destructive earthquake occurred at Purworejo and caused severe damage to buildings; two buildings collapsed. This earthquake was felt at Wonosobo and caused one building to collapse. Also felt at Semarang, Demak, Solotigo and Kendal on the north coast of Central Java. | MMI VIII-IX |
| Origin Time 1843 May 25 | **Bogor**: West Java - a shock was felt at Bogor and caused damage to buildings and houses. | MMI VII-VIII |
| Origin Time 1844 Feb 15 | **Cianjur**: West Java - the earthquake hit Cianjur on West Java and caused damage to houses. | MMI VII-VIII |
| Origin Time 1852 Jan 09 | **Teluk Betung**: South Sumatera - an earthquake tremor was felt in Teluk Betung and caused damage to buildings and houses. | MMI VII-VIII |
| Origin Time 1852 Oct 15 | **Kebumen**: Central Java - a moderate earthquake was felt at Kebumen. This shock caused cracks in walls of several buidings and houses. | MMI VI-VII |
| Origin Time 1852 Nov 26 | **Bandanaira**: Maluku - a strong earthquake was felt at Bandanaira - Banda Island and caused some buildings to collapse. The quake was followed by sea waves (tsunamis). | MMI VIII-IX |

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| Origin Time 1852 Dec 20 | **Bogor**: West Java - a strong earthquake caused some buildings to collapse. | MMI VIII-IX |
| Origin Time 1859 Jul 05 | **Tulungagung**: East Java - an earthquake occurred and some buildings and houses suffered damage. | MMI VI |
| Origin Time 1861 Feb 16 | **Tapanuli and Sibolga**: Numerous houses tumbled down.Tsunami was observed at Singkil, Nias and Tello. | MMI VIII-IX |
| Origin Time 1862 Mar 29 | **Buleleng**: Bali - a moderate earthquake occurred, causing cracks in walls, some of which tumbled down. | MMI VII |
| Origin Time l862 Sept l5 | **Bandanaira**: Maluku - an earthquake caused cracks in walls. | MMI VI |
| Origin Time l862 Nov 20 | **Madiun**: East Java - Damage to a few buildings caused by a rather severe earthquake. | MMI VI |
| Origin Time l863 Aug l3 | **Banyumas**: Central Java - the strong earthquake caused heavy damage to sugar factory. | MMI VII |
| Origin Time l867 Jun l0 | **Yogyakarta**: Central Java - in Jogyakarta and Surakarta 372 houses collapsed or partially collapsed, while 5 persons lost their lives. | MMI VIII-IX |
| Origin Time l87l Mar 27 | **Banyumas**: Central Java - fissures in the walls of government buildings and houses were caused by an earthquake. | MMI VI |
| Origin Time l873 Feb 05 | **Ciamis**: West Java - the walls of numerous buildings cracked. | MMI VI |
| Origin Time l873 Oct 07 | **Tapanuli**: North Sumatera - this quake caused damage to some houses and bridges. | MMI VI |
| Origin Time l877 Feb 2l | **Kedu**: Central Java - a rather strong shock, felt at Kedu and Wonosobo in Central Java, caused damage to several buildings. | MMI VI |
| Origin Time l889 Nov 04 | **Pasuruan**: East Java - the quake caused cracks in walls. | MMI VI |
| Origin Time l890 Jul ll | **Negara**: Bali - the earthquake caused three pillars of the Justice Building to split horizontally and walls to tumble down. | MMI VII |
| Origin Time l890 Nov 23 | **Bandanaira**: Maluku - damage to most of the houses and buildings. | MMI VII |
| Origin Time l896 Jul 0l | **Lumajang**: East Java - the walls of some houses were split. | MMI VI |

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| Origin Time l896 Aug l5 | **Wlingi**: East Java - at Brangah - Wlingi many public and private buildings/houses damaged. | MMI VII |
| Origin Time l896 Aug 20 | **Tulungagung**: East Java - the shock caused severe damage to several Chinese houses. | MMI VII |
| Origin Time l900 Jan l4 | **Sukabumi**: West Java - felt over Priangan, Bogor and Banten. Most damage to stone houses occurred at Sukabumi, but no lives were lost. | MMI VII |
| Origin Time l902 Aug 3l | **Sedayu**: East Java - ground-slumps were observed, walls were disturbed. A series of after-shocks felt during the period 26 Sprt - 9 Oct, the heaviest one on August 3l, accompanied by a roaring sound. | MMI VI |
| Origin Time l903 Feb l4 | **Bandanaira**: Maluku - suspended objects swung and movable objects were thrown down. Siri-Siri: West Sumatera - a part of the pier was destroyed and sailing boats on the coast of Siri-Siri sank as a result of the high waves. | MMI V |
| Origin Time l904 Jul 05 | **Siri-Siri**: West Sumatera - a part of the pier was destroyed and sailing boats on the coast of Siri-Siri sank as a result of the high waves. | MMI VIII |
| Origin Time l907 Jul 30 | **Lemo**: Central Sulawesi - destructive at Lemo, where l64 houses and 49 rice-warehouses collapsed; shocks were frequently felt until August 2. Damage to buildings was also done at Colo, Anja, Olu Congko and Paku. | MMI VIII |
| Origin Time l910 Dec 18 | **Rajamandala**: Cianjur - cracks developed in walls at Rajamandala - Cianjur - West Java. | MMI VIII |
| Origin Time l9l2 Jan 2l | **Campaka**: Sukabumi - cracks developed in walls at Campaka - Sukabumi - West Java. Movable objects were thrown down. | MMI VI |
| Origin Time l9l4 Jun 26 | **Kepahyang**: Bengkulu - all stone houses suffered severe damage. None of the many wooden houses sustained damage. Twenty persons were killed and 20 injured. Roads and bridges were destroyed. Damage was also done at Lais, Manna and Seluma. | MMI IX |
| Origin Time l9l5 Dec 0l | **Madiun**: East Java - nearly all buildings in the Sudono sugar estate were cracked. The chimney of the sugar factory toppled down. A certain amount of damage was also done at Maospati and Magetan. | MMI VIII |
| Origin Time l9l6 Sept 09 | **Maos**: Central Java -most destruction took place in and around Maos. About 340 brick/stone buildings collapsed completely and many others were damaged at Maos and Kasugian. Cracks developed in walls, ground-slumps were reported. A few mud or sand craters were formed where jets of water spurted through holes or fissures causing people to panic. Four hundred houses | MMI IX |

collapsed in the Selarang district. Damage to structures and cracks in the ground were also found in various places. School buildings were among those most generally and severely damaged, due in considerable part to unsuitable design for resistance to shaking. The major destruction, however, was in a more thickly settled district, where unfavourable geological conditions and poor structural work increased the damage.

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| Origin Time l9l7 Jan 2l | **Bali**: Ground-slumps and ground-slides were observed at various places. Many houses suffered damage and about l500 people were killed due to ground-slides. | MMI IX |
| Origin Time l92l Apr 0l | **Tapanuli**: North Sumatera - epicentre tract occupied a narrow belt aligned north west-south east running for some 80 km from Pangururan to Tarutung. The area worst hit was the region southwest of Lake Toba. Buildings and bridges collapsed at Sipoholon; furthermore, ground-slides and ground-slumps were reported. The quake also felt as far as Sabang, Penang and Gunung Sitoli. | MMI IX |
| Origin Time l923 May l5 Epicentre 7.7°S-l09.2°E | **Maos**: Central Java - the shock was felt intensively over western Central Java. Destructive effects were particularly pronounced in and around Maos. | MMI IX |
| Origin Time l924 Nov l2 Epicentre 7.3°S-l09.8°E | **Central Java**: The centre was located in a mountainous region. Damage was generally caused by ground-slides. | MMI VIII-IX |
| Origin Time l924 Dec 02 Epicentre 7.3°S- l09.9°E | **Wonosobo**: Central Java - the quake seemed to be preceded by foreshocks. Destructive at Wonosobo and damage was also done to stone buildings outside Wonosobo. Approximately 2250 houses collapsed and in some villages most damage was caused by ground- slides. Altogether about 727 people were killed. The quake loss was estimated by the local authorities at about 6l,000 guilders. | MMI IX |
| Origin Time l926 Jun 28 Epicentre 0.7°S-l00.6°E | **Singkarak:** West Sumatera - destructive around Lake Singkarak; Sijunjung, Muarabungo and Alahan Panjang suffered damage. The quake was followed by a train of aftershocks. These tremors were generally felt intensively over West Sumatera and in particular at Padangpanjang. A part of Lake Singkarak subsided and many people were injured. | MMI IX |
| Origin Time 1926 Dec 1 | **Prupuk**: Central Java - destructive at Prupuk and Margasari, minor damage at Dubuktengah, Kaligayan, Wonosari, Danurejo, Jambayat, Pakulaut and Kalisosok. A few people were injured. | MMI VIII-IX |

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| Origin Time 1930 Apr 27 | **Bali**: Exact origin was unknown. Damage was done in south Bali by a moderate tremor. Walls were cracked at Denpasar and Tabanan, earth fissures in the ground occurred at Benoa. The shock was also felt over East Java. | MMI V |
| Origin Time 1931 Jan 21 Epicentre 7.3°S- 108.9°E | **Bumiayu**: Central Java - in general, damage was confined mostly to older structures of buildings of poor materials and poor construction. | MMI VIII |
| Origin Time 1933 Jun 25 Epicentre 5.5°S- 104.2°E | **South Sumatera**: The quake seemed to have been followed by a number of aftershocks. Damage to structures over the western part of South Sumatera. Gaping fissures and subsidences in the ground were observed along an imaginary line connecting Kotaagung with Makaka, crossing the Barisan mountain range (Bukit Barisan). | MMI VIII-IX |
| Origin Time 1934 Sep 31 Epicentre 1.0°N-99.0°E | **South Tapanuli**: Sumatera - generally felt violently. Pendulum clock stopped; doors and windows rattled. Cracks developed in walls, roofs of some houses ruined. | MMI VII |
| Origin Time 1935` Dec 28 Epicentre 0.3°S-97.9°E | **Batu Island**: North Sumatera - damage on Batu Island. Two mud islets, Bola dn Sigata, were thrown up by the shock. At Padang cracks developed in walls. Trees and telephone poles swayed. A few buildings collapsed at Sibolga. | MMI VII-VIII |
| Origin Time 1936 Mar 01 | **East Java**: Exact origin unknown. Damage was generally done in Central and East Java. The shock was also felt over Bali and southeast Kalimantan. | MMI VII |
| Origin Time 1936 Sep 09 Epicentre 3.5°N- 97.5°E | **Tapanuli**: North Sumatera - the quake caused minor damage at Medan and it was felt as far east as Malaysia. The most destructive effects of the quake were confined to the Karo region; 17 people were killed due to landslides in the hills. Numerous cracks appeared in the ground between Kutacane and Kebanjahe. A certain amount of damage at Parapat, Brastagi, and Tanjung Putri. Cracks developed in walls at Langkat. | MMIM VIII |
| Origin Time 1936 Oct 27 Epicentre 0.2°S-98.8°E | **Tapanuli**: North Sumatera - the quake was felt over Tapanuli, West Sumatera and also locally in East Sumatera. At various places slight damage to structures and ground-slumps were reported. | MMI VII |

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| Origin Time 1937 Sep 27 Epicentre 8.7°S-110.8° | **Yogyakarta**: Central Java - felt as far east as eastern Lombok. In general, south Central Java was badly damaged and slight cracks in walls were found in East Java. The region of greatest destruction in Yogyakarta Province. At Klumpit one house was torn apart, one person reported killed. At Prambanan 326 brick/stone houses collapsed. At Klaten 2200 houses sustained damage; at various places underground pipelines were broken. | MMI VIII-IX |
| Origin Time 1938 Feb 02 | **Banda**: Malukuk - the shock was felt in the Banda and Kei islands.At Tual glassware was broken, a pendulum clock stopped. On Banda Island and also on Kei Island great damage was caused by tsunami. | MMI VII |
| Origin Time 1938 Oct 10 Epicentre 8.9°S-115.8°E | **Bali**: As a result of the shock, cracks appeared in walls and the principal mosque was badly damaged at Sukara | MMI VII |
| Origin Time 1943 Jul 23 Epicentre 8.6°S-109.9°E | **Yogyakarta**: Central Java - the disturbance was most intense along the south coast of Central Java, between Garut and Surakarta, a distance of about 250 km. The deaths of 213 people were reported and about 2096 persons were seriously injured; approximately 2800 houses were damaged. | MMI VIII |
| Origin Time 1954 Nov 02 08h 24m 54s UTC Epicentre 8.0°S-119.0°E Magnitude: 6.75 | **Bima**: Sumbawa - felt over South Sulawesi, Lombok and Flores. Ground-slumps and rock-slides were caused by the earthquake in northeast Sumbawa. Bima and Raba suffered most damage. Nearly all brick/stone houses were cracked and some collapsed completely. Two buildings made of reinforced concrete did not sustain any damage. The pier of Bima harbour was bent outward. A small Custom house seemed to be displaced over a distance of about 0.5 m. No lives were lost. | MMI VII-VIII |
| Origin Time 1958 Oct 20 01h 12m 30s UTC Epicentre 9.5°S-112.5°E Magnitude:6.7 Depth: 100 km | **Malang**: East Java - seriously damaged houses in the Malang area. Earth fissures at various places and land-slides in the mountainous regions. Eight persons lost their lives. | MMI VII-XIII |
| Origin Time 1960 Oct 10 21h 44m 40s UTC Epicentre 8.0°S-112.5°E | **Tulungagung**: East Java - the quake was strongly felt at Tulungagung, where people were awakened by cracking of buildings and where plaster cracked and fell. The shock was felt as far west as Baturetno in Surakarta and as far east as Tanggul in Besuki. This earthquake was widely felt in southern East Java over an area of about 15,000 square km. | MMI VI-VII |

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| Origin Time 1961 May 07 04h 32m 05s UTC Epicentre 8.5°S-122.0°E | **Campurdarat**: East Java - damage to brick buildings at Campurdarat and Kebonagung, Tulungagung. Reports indicated that the microseismic area extended as far west as Banyumas, Central Java and as far east as Besuki in East Java. Evidence indicated that the tremor had a maximum intensity of VII in the immediate vicinity of the centre. The shock also felt at Jatisrana-Surakarta, Klaten, Maos, Malang and Klasah. To the north the microseismic area was limited by the mountain range Kendeng; however some places like Demak and Watubelang to the north of the mountain range felt this tremor as Intensity II. The great macroseismic extent suggested that the quake was deep-seated. In the vicinity of the centre slight damage was caused to old structures made of bricks bonded with lime mortar. | MMI VI-VII |
| Origin Time 1962 Dec 21 00h 44m 19.7s UTC Epicentre 9.0°S-112.2°E Depth: 64 km | **Wlingi**: East Java - cracks in walls in southern East Java. The shock was felt as far east as the island of Bali. A moderate tremor was felt in Wlingi and neighbouring place in Kediri and also felt in most places in Madiun area. A large number of people in buildings in Madiun and Kediri felt the quake and its intensity was high enough to cause some panic in public places, such as schools and markets. Macroseismic and instrumental data indicated that the tremor was of tectonic nature and deep- focussed. | MMI VI |
| Origin Time 1963 Jun 27 11h 46m 58s UTC Epicentre 08.3°S-112.2°E Depth: 180 km | **Ponorogo**: East Java - the earthquake caused slight damage in Ponorogo. The shock was felt in central and eastern Java. The westernmost place was Yogyakarta and the cast, Besuki, which detected the tremor; both places reported Intensity II. | MMI II |
| Origin Time 1963 Dec 16; 02h 45m 35s UTC, Epicentre 06.2°S- 105.4°E, Magnitude: 5.0 Depth: 55 km | **Labuan**: West Java - the earthquake caused slight damage in Labuan where cracks developed in walls. A large number of people felt the quake and its intensity was high enough to cause some panic among the people in Jakarta; however, no damage was reported from this shock. The seismograph of the Meteorological Service was out of order. The shock was felt as far east as Tasikmalaya as intensity II and as far west as Kotabumi in South Sumatera as Intensity II. The shock was also felt in most places in Priangan as Intensity II-III. | MMI V |
| Origin Time 1965 Jan 25; 12h 02m 51.4s UTC, Magnitude: 6.3 Depth: 33 km | **North Maluku**: A rumbling sound was heard at Sanana. Coastal villages destroyed and 5 persons reported killed, due to a tsunami. | MMI VII |

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| Origin Time 1967 Feb 19; 22h 14m 55s UTC, Epicentre 8.5$^{o}$S- 113.5$^{o}$E, Magnitude: 6.2 Depth: 80 km | **Malang**: East Java - the place worst hit was Dampit, a district situated just to the south of Malang; according to questionnaire reports, 1539 buildings were wrecked, 14 people were killed, 72 people were injured. Next to Dampit was Gondang where, according to a report, 9 people were kolled, 49 people were injured, 119 buildings collapsed completely and another 402 buildings were cracked, 5 mosques were ruined. Attention should also be drawn to Trenggalek where 33 wooden houses were reported cracked and some houses moved slightly. In Besuki, the easternmost district of East Java, the intensity was of the order of III to VI MMI; in Tanggul buildings sustained slight damage only. The shock was felt to the west as far as Banyumas (Cilacap); to the north a chain of hills in western East Java form a sort of barrier to the propagation of seismic waves. No report was received about a tsunami. | MMI VII-VIII |
| Origin Time 1967 Apr 11; 05h 09m 11s UTC, Epicentre 03.7$^{o}$S- 119.3$^{o}$E, Magnitude: 4.9 Depth: 51 km | **Tinambung**: South Sulawesi - the tremor was felt over a wide area. The area worst hit covered from coastal lowlands extending from Campalagian to Tinambung. A high tsunami was generated during the main shock causing serious loss of life and property in coastal villages; 58 people were reported killed by the collapse of brick buildings, about 100 people were injured, 13 people were drowned in the sea or missing. Fissures were local in nature and might have been due to the loose formation of the soil in that area. | MMI VII-VIII |
| Origin Time 1968 Aug 14; 22h 14m 15s UTC, Epicentre 0.7$^{o}$N- 119.8$^{o}$E, Magnitude: 6.0 Depth: 23 km | **Tambu**: Central Sulawesi - generally along the west coast of the northern part of Central Sulawesi an increase of high waves was noticed shortly after the main shock, in particular in Tambu Bay; the wave height in Tambu was about 8 to 10 m and might have reached some coconut-tree tops; the waves swept further inland, to about 100-300 m from the coast. Most of the beach of the inner part of Tambu Bay was under sea water; slumps, with surface trace of faulting and hot springs in several places were observed Loss of life and considerable damage were chiefly caused by the tsunami along the coast of Mapaga (200 people killed and missing, 790 wooden houses wrecked). In Tambu 7 wooden houses on pillars moved in a northwesterly direction. In Sabang a roaring sound was reported. Small island of Tuguan is uninhabited and remained intact. The main shock seemed to be followed by aftershocks and one of those was shallow (11 km). A report from Central Sulawesi about a sound that was also heard in Tambu on October 19, 1968 would strengthen the report of earthquake which was deteced at 0.1oN-119.8oE in Mapaga Bay. | MMI VII-VIII |

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| Origin Time 1969 Feb 23, 00h 36m 55.6s UTC, Epicentre 02.1°S - 118.5°E, Magnitude: 6.1 Depth: 13 km | **Majene**: South Sulawesi - this quake killed 64 people, 97 others were injured and about 1287 manmade structures were wrecked including mosques which competely collapsed due to poor construction. The place worst hit was Majene. Eighty percent of the brick buildings sustained serious damage; some of them completely collapsed. The pier of the harbour was cracked in several places possibly due to a subsidence of the submarine surface just outside the harbour; gaping cracks, about 50 m long, caused three brick buildings serious damage; the centre market completely collapsed resulting in several deaths and severe property damage. Campalagian and Wonomulyo, located on alluvium and respectively about 30 km and 50 km east of Majene, also sustained structural damage. General wooden houses were able to resist the shaking and much of the damage there was caused by the collapse of unreinforced concrete walls. A tsunami generated by the quake struck the coastal villages north of Majene. The wave height reached about 4 m at Parasanga and Pilili. The construction in the villages was principally wood frame and, due to their location at the end of a bay, the wooden houses were swept away by the tsunami. In these coastal places banana trees were almost totally destroyed. Damage to the mosque was probably due to the fact that the old structures were made of brick without reinforcing iron rods. Several bridges were damaged in this narrow lowland plain. Between Somba and Parasanga great blocks of Neogene marls and tuffs tumbled down and in some places the road was buried by these blocks. Also from the edge of the raised coral reefs greater and smaller parts were loosened and tumbled down onto the beach. Fissures were also oberved at several places. People interviewed said a roaring sound was heard coming from the sea. The shock was felt as far south as Ujungpandang. | MMI VIII |
| Origin Time 1969 Nov 02; 18h 53m 6.6s UTC, Epicentre 6.5°S- 107.1°E Magnitude: 5.4 Depth: 57 km | **Sukabumi**: West Java - a relatively strong earthquake was felt in southern West Java. In the Bogor area suspended objects swung as a result of the shocks; in Campaka, where the intensity was highest, the only known structural damage was cracks produced in the walls of some badly constructed buildings. The shock was also slightly felt in Jakarta. In the south Bogor area an aftershock seemed to be felt one hour later. In Sukabumi a poorly-constructed brick building was reported collapsed as a result of this earthquake. | MMI V |

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| Origin Time 1971 Feb 04; 15h 33m 22s GMT Epicentre 0.6ºN-98.8ºE Magnitude: 6.3 Depth: normal | **Sibolga**: North Sumatera - damage to brick buildings developed in Pasaman, Natal, Pinangsore, Sibolga and Pasir Ulu estate. Fissures were observed in Sibolga and hot springs developed in Tarutung. The shock was generally felt in various places in the eastern part of north Sumatera and as far east as Singapore. No loss of life was reported from this earthquake. | MMI V-VI |
| Origin Time 1972 Sept 06; 08h 00m 25.3s UTC Epicentre .5ºS- 119.1ºE Magnitude: 5.8 Depth: 36 km | **Mamuju**: South Sulawesi - the quake rocked the Mamuju area in the northwestern part of south Sulawesi. Only slight damage to brick buildings resulted from the tremor. The quake was preceded by a roaring sound similar to that of a bomb. The shock was felt as far south as Majene. | MMI IV |
| Origin Time 1972 Nov 04; 21h 36m 54.0s Epicentre 8.4°VS-112.2°VE East Java: Magnitude: 6.0 Depth: 126 km | **Southern Blitar** - Trenggalek area experienced an earthquake at 04h 36m L.T. in the morning. Gandusari reported a fairly strong shock as Intensity V-VI MMI. The tremor caused cracks in the walls of brick buildings and a great number of people were awakened from sleep. The shock was felt as far as the Yogyakarta - Surakarta border and this far- extended felt area strengthened the view that the shock was deeper than normal. | MMI V-VI |
| Origin Time 1972 Dec 19; 14h 47m 00.0s UTC, Epicentre 06.9ºS-107.8ºE Magnitude: 4.5 Depth: very shallow | **Sumedang**: West Java - at 21h 47m L.T. on December 19th, 1972 the Sumedang area experienced a tremor of moderate strength which was slightly shallower than normal, as indicated by the small area affected. The quake caused slight damage to old brick buildings and panic among the people. In Cibunar, Rancakaleng and Pasaribu villages the intensity was IV MMI. In Sindang village the same quake was felt as V MMI; ground-slides and ground fissures were observed. | MMI V |
| Origin Time 1974 Nov 09; 19h 10m 55.2s UTC Epicentre 6.5ºS- 105.3ºE Magnitude: 6.1 Depth: 51 km | **Banten**: West Java - this quake caused people to awaken. In Leuwiliang, southern Banten, one stone building collapsed and cracks developed in the walls of some houses. The shock was felt as far as Lampung and Pringsewu in South Sumatera and also in Jakarta by some people. | MMI VI |
| Origin Time 1975 Jan 15; 09h 42m 24s UTC Epicentre 5.0ºS- 130.0ºE Magnitude: 5.9 Depth: Normal | **Banda Island**: Maluku - heavy damage at Bandanaira, 81 houses seriously damaged, 4 houses moderately damaged and 2 houses slightly damaged. The earthquake was followed by a tsunami. | MMI VII |

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| Origin Time 1975 Mar 05; 00h 22m 23s UTC Epicentre 02.4ºS-126.1ºE Magnitude: 6.5 Depth: normal | **Sanana** : Sulu Island - the shock felt by many people in Sanana - Sulu Island at 01.30 UTC for 8 seconds and at 02.24 UTC for 1.5 seconds. Cracks in walls and plaster falling. The earthquake was followed by a tsunami. The height of sea water was about 1.20 m; it reached the road in Sanana, and caused people to panic. No persons killed. | MMI VI |
| Origin Time 1975 Jul 30; 09h 17m 11.6s UTC Epicentre 9.9ºS-123.9ºE Magnitude: 6.1 Depth: 30-50 km | **Kupang**: Timor Island - the walls of many houses fell, cracks in walls, plaster fell. No damage to buildings or houses of good construction. The earthquake was followed by a sound like thunder from the ground. | MMI VII |
| Origin Time 1976 Feb 14; 20h 31m 49s UTC Epicentre 7.2ºS- 109.3ºE Magnitude: 6.1 Depth: 30-50 km | **Purwokerto**: Almost everyone was awakened from sleep due to the earthquake and the sounds from the buildings/houses. The shock was also felt at Ajibarang Kedungbanteng, Tegal, Brebes, Pekalongan, Magelang and Semarang. No damage reported. | MMI IV |
| Origin Time 1976 Jun 25; 19h 18m 55.5s UTC Epicentre 4.6ºS-139.8ºE Magnitude: 7.0 Depth: 33 km | **Bime, Eipomek, Nalca and Okbad in Irian Jaya:** Severe damage occurred in Langda, Ambon, Japil, Oksibil. Due to the lack of transport and communications no complete report available. | MMI VIII |
| Origin Time 1976 Jul 14, 07h 13m 22s UTC Epicentre 8.2ºS- 114.9ºE Magnitude: 6.2 Depth: normal | **Sepirit and Busungbiru**: 90% brick buildings and houses collapsed. In Tabanan and Jembrana more than 75% buildings and houses severely damaged, 559 people killed, 850 people seriously injured and more than 3200 injured. | MMI VIII |
| Origin Time 1976 Oct 29; 02h 51m 01s UTC Epicentre 4.7ºS- 140.2ºE Magnitude: 6.0 Depth: 30-50 km | **Nalca**: Bime - 62 people killed. At Landa, 46 people killed. The wooden houses of native people which were built on the slope, collapsed and were buried by a landslide, but the wooden houses which were built on the flat ground suffered no damage. | MMI VIII |
| Origin Time 1977 Jan 26; 13h 11m 29.5s UTC Epicentre 8.25ºS- 115.3ºE Magnitude: 5.0 Depth: normal | **Bangl**i: Bali - this relatively strong quake was felt in Bangli and surroundings. In Kayubihi village cracks were produced in the walls of one semi-permanent school building; a monument and temple collapsed. About 90% of houses damaged. In Banjar Antugan Jehem village more than 80% of buildings and houses cracked. Ground-slides and cracks in the ground were observed in the Melangit River, about 500 m eastward of Kayubihi and Antugan. No killed or injured reported. | MMI VI |

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| Origin Time 1977 Mar 08; 23h 17m 29s UTC Epicentre 0.4ºN-99.7ºE Magnitude: 6.0 Depth: normal | **Pasaman**: West Sumatera - in Sinurut the quake caused serious damage to 737 houses, one market, 7 school buildings, 8 mosques also damaged. Almost all wooden houses in that area were slanted and shifted from their foundations. Cracks in the ground 5-75 cm wide were observed. The quake was felt at Padang and Padangpanjang with intensity of III MMI. No killed or injured reported. | MMI VIII |
| Origin Time 1979 Apr 28; 03h 29m 55.5s UTC Epicentre 0.7ºS-99.5ºE Magnitude: 5.7 Depth: normal | **Marapi**: West Sumatera - the quake caused cracks in some houses in Pinangsore - Sibolga. The shock also felt in Padang, Padangpanjang, Bukittinggi, Batusangkar and caused people to panic. Two days after, at midnight on April 30, the Marapi disaster occurred, because materials such as stones and soil crashed down from the top and slopes of the mountain. The materials from Marapi washed away everything and resulted in 64 people killed, 9 people missing, 193 houses collapsed, 42 bridges damaged, 138 dam and irrigation schemes destroyed, 34 cattle killed. The disaster might have been caused not only by the quake but also by the heavy rain in Marapi and the surrounding district. | MMI V |
| Origin Time 1979 May 30, 09h 38m 53s UTC Epicentre 8.21ºS- 115.95ºE Magnitude: 6.1 Depth: 25 km | **Lombok**: Nusatenggara - in Tanjung many houses and buildings collapsed, especially the poorly designed structures and old houses/buildings. Some people killed and injured. Other affected areas were Buyan, Gangga, Kediri, Cakranegara, Narmada, where many buildings and houses were also seriously damaged and some even collapsed. Two mosques in Narmada and Cakranegara suffered moderate damage, cracks developed in their walls. The tower of the mosque in Kediri cracked. In Ampenan and Mataram the quake caused only slight damage to houses/buildings. In fact the damage to houses/buildings was due to old or poor construction. | MMI VIII-IX |
| Origin Time 1979 Oct 20, 01h 41m 09s UTC Epicentre 8.25ºS-116.0ºE Magnitude: 5.8 Depth: normal | **Karangasem**: Bali - the quake caused moderate damage to buildings and houses in Karangasem, Ampenan, and Mataram on Lombok Island, eastward of Bali. | MMI VI |
| Origin Time 1979 Nov 02, 15h 53m 2.6s UTC Epicentre 8.6ºS-107.8ºE Magnitude: 6.4 Depth: 64 km | **Tasikmalaya**: West Java - in Tasikmalaya and surroundings the quake caused 163 houses and buildings to collapse; 1430 houses were seriously damaged; one meeting hall and 24 school buildings were damaged, 3 mosques collapsed and 29 were seriously damaged; 159 news-stands were severely damaged. | MMI VII |

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| | In Garut most old and poorly constructed stone houses collapsed; many permanent houses had cracks in walls; 10 people killed, 12 seriously injured. Cracks in the ground in an east-west direction were observed. The quake was accompanied by a roaring sound from under the ground. Abnormal sea tides were observed 2 days before the quake occurred in Pameungpeuk. | MMI VII |
| Origin Time 1979<br>Dec 17, 19h 58m 26s<br>UTC Epicentre<br>8.4ºS- 115.8ºE<br>Magnitude: 5.0<br>Depth: 28 km | **Karangasem**: Bali - in Karangasem this earthquake killed 5 persons, seriously injured 34 and slightly injured 250. Some houses collapsed, some were seriously damaged, many slightly damaged. In Abang, 17 people killed, 9 seriously injured, 300 slightly injured. Some houses collapsed, others seriously or slightly damaged. In Culik, many houses collapsed. In Kubu, one person killed, 2 persons seriously injured and 18 slightly injured. Most buildings seriously or slightly damaged, but no building collapsed. In Bebandem, one person killed, 2 seriously injured and 4 slightly injured. Buildings and houses seriously or slightly damaged. Cracks in the road and land were observed along 0.5 km. | MMI VI-VIII |
| Origin Time 1980<br>Apr 16, 12h 18m 19s<br>UTC Epicentre<br>8.25ºS-108.8ºE<br>Magnitude: 6.4<br>Depth: normal | **Tasikmalaya**: West Java - in Singaparna many houses had cracks in walls but in Tasikmalaya itself only some houses were cracked. In Garut and surroundings the poorly constructed houses had cracks in walls, also in the district of Sukawening, Pasanggrahan, Jamberea, Cari-ngin, many cracks developed in walls. In the Singajaya district 10 elementary school buildings slanted. The quake also caused cracks in houses in Cilacap, Central Java. The shocks were felt in Bandung at Intensity III. | MMI V-VI |
| Origin Time 1981<br>Jan 01, 02h 09m 52s<br>UTC Epicentre<br>7.7ºS-111.0ºE<br>Magnitude: 6.0<br>Depth: shallow | **Karanganyar**: Central Java - the quake shook Karang-anyar and surroundings and caused slight damage to some houses. | MMI VI |
| Origin Time 1981<br>Mar 13, 23h 22m 35s<br>UTC Epicentre<br>8.95ºS-110.4ºE<br>Magnitude:6.0<br>Depth: normal | **Yogyakarta**: Central Java - the shock was felt in Yogyakarta and caused small crakcs in the walls of the Ambarukmo Hotel. No other buildings or houses damaged. | MMI VII |
| Origin Time 1982<br>Feb 1, 09h 17m 50.2s<br>UTC Epicentre<br>7.0ºS-106.9ºE<br>Magnitude: 5.3<br>Depth: 25 km | **Sukabumi**: West Java - the quake was felt in some places in the Sukabumi and Bogor areas. The shock caused serious or slight damage to many houses and buildings and 4 people were injured. No loss of life. | MMI VII |

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| Origin Time 1983 Oct 16, 05h 32m 24.8s UTC Epicentre 1.48°N- 121.01°E Magnitude: 5.9 Depth: 46 km | **Toli-toli:** Central Sulawesi - according to the news in the Kompas Newspaper, on October 21, 1983 the quake caused 20 houses in Toli-toli to collapse and 15 aborigine's houses were seriously damaged. | MMI VI |
| Origin Time 1983 Oct 25, 00h 36m 19.4s UTC Epicentre 1.6°N- 120.8°E Magnitude: 6.0 Depth: 50 km | **Central Sulawesi**: The quake was strong enough to cause 2 people killed, 4 injured and 24 houses to be seriously damaged, of which 20 collapsed. The shock was also felt in Palu, the capital of Central Sulawesi Province. | MMI VII |
| Origin Time 1984 Jan 08, 15h 24m 14.4 s UTC Epicentre 2.94°S- 118.73°E Magnitude: 5.9 Depth: 95 km | **Mamuju**: Central Sulawesi - this quake killed 2 persons, seriously injured 5, slightly injured 84. In the affected area 15 government office buildings, 23 government houses, 31 school buildings, one clinic, one news-stand seriously damaged and about 16 government office buildings, 12 government houses, 14 school buildings and two clinics slightly damaged. Besides the above mentioned damage, 213 local people's houses, 4 shops, 18 mosques and 1 church were seriously damaged. Ground-slumps were observed in Tapalang. The shock was also accompanied by a tsunami. | MMI VII |
| Origin Time 1984 Aug 27, 06h 41m 25.5s UTC Epicentre 1.5°S- 98.94°E Magnitude: 4.8 Depth: 53 km | **Pahae Jae - Tapanuli**: North Sumatera - in Sarula, three elementary school buildings and one junior high school building collapsed, one senior high school building was seriously damaged and the school caretaker's house shifted 30 cm from its foundations. Cracks developed in the walls of the local authority office, post office building, clinic. In Perdamaian and Selangkitang villages two elementary school buildings partly collapsed. Ground-slides were observed. On the road between Tarutung and Padangsidempuan cracks in the ground developed and sulphurous gas was emitted. In Pinangsori-Sibolga small cracks developed in the walls of houses. The quake was felt as far as Gunung Sitoli on Nias Island, Rantau Prapat and Balige (Toba Lake). According to the news, the shock was also felt along the west coast of Malaysia. | MMI VIII |

## d. Zone 4

| Event | Felt | I max |
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| Origin Time 1821 Dec 25 | **Jepara**: Central Java - the earthquake was felt at Jepara and reported as VI-VII on the MMI scale. | MMI VII |
| Origin Time l833 Jan 28 05h 00m 00s | **Batavia/Jakarta**: Shocks caused damage to buildings and cracked walls. No deaths or injuries were reported. | MMI VII-VIII |
| Origin Time l836 Mar 22 | **Mojokerto**: East Java - at Mojokerto, about 60 km west of Surabaya, a shock occurred and caused damage and loss of property. | MMI VII-VIII |
| Origin Time l853 Nov l0 | **Cirebon**: West Java - a moderate earthquake was felt and caused cracks in walls. No further information. | MMI VII-VIII |
| Origin Time l856 Jan l9 | **Semarang**: Central Java - an earthquake was felt at Semarang and caused cracks in walls. | MMI VII-VIII |
| Origin Time l862 May 24 | **Karawang**: West Java - a rather severe shock was felt at Karawang, West Java, where walls of some houses were fissured. | MMI VI |
| Origin Time l865 Jul l7 | **Banyubiru**: Central Java - some buildings and houses suffered considerable damage by the earthquake. | MMI VII |
| Origin Time l866 Apr 22 | **Ambarawa**: Central Java - because of an earthquake, walls of some houses and barracks were fissured. | MMI VI |
| Origin Time l872 Oct l0 | **Salatiga:** Central Java - a rather strong shock felt at Salatiga caused fissures in walls. | MMI VI |
| Origin Time l873 Aug l9 | **Mandailing**: North Sumatera - many houses were damaged due to the earthquake. | MMI VI |
| Origin Time l875 Oct 25 | **Kuningan**: West Java - the quake was felt at Kuningan, Sumedang and Manonjaya. 628 houses damaged and seven people killed. | MMI VII-VIII |
| Origin Time l890 Dec l2 | **Pati**: Central Java - this quake also felt at Juwana; caused many houses to fall. Several people killed and injured. | MMI VIII |
| Origin Time l892 May l7 | **Prapat**: North Sumatera - the shock caused severe damage to three buildings. | MMI VI |

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| Origin Time l92l May l4 | **Sangkulirang**: East Kalimantan - damage at Sangkulirang and more intense on the islands of Rending, Kaliorang and Sekuran. Houses collapsed and gaping fissures were observed. The shock was associated with a tsunami which swept the sea, causing considerable damage at Sekuran. | MMI VIII |
| Origin Time l923 Apr l9 | **Tarakan**: East Kalimantan - the earthqukae was recorded by sensitive seismographs all over the world. The shock was strongly felt at Tarakan about l40 km north of the centre and was followed by a number of aftershocks. Brick buildings collapsed, cracks developed in the ground, and streams were affected. The kitchen of a house seemed to be displaced over a distance of about l m toward the west. Structures on solid ground suffered little damage. | MMI VIII |
| Origin Time l924 Apr l3 Epicentre 0.3$^{o}$N-ll8.2$^{o}$E | **East Kalimantan** - the tremor was generally felt at several places in East Kalimantan and as far north as the island of Tarakan. It was followed by aftershocks. As a result of the main shock, seven houses collapsed. | MMI VII |
| Origin Time l925 Feb l4 | **Tarakan**: East Kalimantan - the exact origin was unknown, but the shock was strongly felt at Tarakan and Lungkas and it was preceded by a rumbling sound. | MMI VII |
| Origin Time l927 Dec 0l Epicentre 0.5$^{o}$S-ll9.5$^{o}$E | **Donggala**: Central Sulawesi - a major earthquake caused damage to buildings at Donggala, Borowaru and neighbouring places. Earth fissures and subsidences in the ground were reported. The damage was mainly confined to the Palu Bay area. A tsunami was observed that caused serious loss of life and property in coastal villages. About 50 people sustained injuries and 50 died. | MMI VII |
| Origin Time l936 Oct l9 Epicentre 2.0$^{o}$S-l26.0$^{o}$E | **Sanana**: Molluca - aftershocks were also felt on Sula Island. Movable objects were overthrown and a rumbling sound was heard. At Sanana, 24 houses collapsed, great fissures appeared in the ground close to the market. At Wai Ipa, l4 houses were damaged and at Wai Iau 2 buildings sustained considerable damage. | MMI VIII |
| Origin Time l939 Jun 27 Epicentre 6.9$^{o}$S-l08.5$^{o}$E | **Central Java**: Fall of plaster and small cracks in walls in the Cirebon Residency. More damage was done at Sodomantra, Japara and Manis Kidul. | MMI VII |
| Origin Time l939 Aug ll Epicentre 6.5$^{o}$S-ll2.4$^{o}$E | **East Java**: Kembang and Surabaya were rocked; suspended objects swung. A brick building collapsed at Brondong. | MMI VII |

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| Origin Time l950 un l9; l2h 36m 54s UTC Epicentre 6.2°S-ll2.5°E | **East Java**: Destructive in and around Gresik. Felt slightly in South Kalimantan and as far west as West Java. | MMI VII |
| Origin Time l965 Jul 25 03h 40m 40.4s GMT Epicentre 2.0°N-99.3°E Magnitude: 5.3 Depth: 98 km | **Tapanuli**: North Sumatera - at Sarula and Onang Hasang in Tapanuli the intensity reached VII MMI; damage to brick buildings and ground-slumps were observed. | MMI VII |
| Origin Time l97l Jun l6 l4h 44m 22.5s Epicentre .2°S-l09.l°E Magnitude: 5.2 Depth: 35 km | **Bantar Kawung**: Central Java - the shock was generally felt in western Central Java. The place worst hit was Buaran, about 6 km west of Bumiayu; further, in Bantar Kawung and Jipang, respectively some l2 and l7 km west of Bumiayu, most brick buildings suffered considerable damage. In the affected area l377 buildings sustained damage; wooden houses generally resisted shaking but some poorly constructed buildings slanted toward east or west and some collapsed completely. Despite this only one person was reported killed and 6 injured. The damage might have been due to old structures made of brick which are not well cemented and are withouth reinforcing iron rods. The unconsolidated river deposits may largely be responsible. | MMI VII-VIII |

## 4. Destructive Earthquakes during 1984-1995

### Zone 5

| Event | Felt | I max |
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| 1984 Jan 08<br>Epicentre: 2.9ºS 118.73ºE,<br>Magnitude : 5.9<br>Depth: 95 | **Sulawesi** : Mamuju - 2 people killed, 5 badly injured, 84 slightly injured, more than 800 buildings damaged and collapsed. | MMI VII |
| 1984 Aug 27,<br>Epicentre: 1.5ºN - 98.94ºE | **Sumatera**: North Sumatera - damaged area at Sarula, Silangkitang, Perdamaian, landslide at Tarutung. | MMI VIII |
| 1987 Apr 27,<br>Epicentre: 2.1ºN-98.8ºE,<br>Magnitude: 5.9,<br>Depth: 30 | **Sumatera**: North Sumatera - land cracked at Tarutung valley | MMI VII |
| 1987 Nov 26,<br>Epicentre: 8.4ºS-124.8ºE,<br>Magnitude: 5.8,<br>Depth : 28 | **Nusa Tenggara** : Flores - hundreds of houses collapsed, 44 people killed, 65 people badly injured and 42 slightly injured. | MMI VII-VIII |
| 1989 Jul 15,<br>Epicentre: 7.3ºS - 124.8ºE | **Nusa Tenggara** : Alor - damaged at east Alor, 7 people injured, 29 houses collapsed and 90 buildings damaged. | MMI VIII |
| 1989 Aug 12,<br>Epicentre: 4.5ºS-138.95ºE,<br>Magnitude: 6.0<br>Depth: 25 km | **Irian Jaya**: Kurima - tens of people killed, buried by landslide triggered by earthquake. | MMI VIII-IX |
| 1990 Apr 18,<br>Epicentre 1.12ºN -122.48ºE,<br>Magnitude: 7.0<br>Depth 45 km | **Sulawesi**: Gorontalo - Liquefaction. Damage at Gorontalo, Atingola and Inobonto. | MMI VIII-IX |
| 1990 Jul 6,<br>Epicentre: 6.55ºS -106.20ºE,<br>Magnitude: 5.8<br>Depth: 25 km | **Java**: West Java - 8000 buildings collapsed at Wanahayu, Cengal and Sukamenak. Land cracked about 10 km. | MMI VII-VIII |
| 1990 Nov 15,<br>Epicentre: 3.6ºN - 96.34ºE,<br>Magnitude: 5.0<br>Depth: 33 km | **Sumatera**: Aceh - damage at Blangkejeren, Agusen, Kutapanjang, Rikit Gaib, Rawung, Gumpang and Kutacane. | MMI VII-VIII |

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| 1991 Jul 4, Epicentre 10.2ºS -126.36ºE, Magnitude: 6.7 Depth: 33 km | **Nusatenggara:** Alor - 22 people killed, 181 injured, 1177 buildings damaged, 1080 people homeless. | MMI VIII-IX |
| 1991 Feb 4, Epicentre 7.2ºS -109.1ºE, Magnitude: 5.0 Depth: 10 km | **Java**: Central Java - over 800 houses damaged and collapsed at Pengarasan, Jetak, Jipang, Kebandungan, Ciomas and Bantarkawung. | MII VII-VIII |
| 1992 Dec 12, Epicentre 8.8ºS - 122.1ºE, Magnitude: 7.5 Ms Depth: 23 km | **Nusatenggara**: Flores - 2080 people killed, 67 people missing, 2103 people injured. Material loss about 250 billion rupiahs. Disaster at northern coast of the island, Ende, P. Babi, P. Pomana, Tanjungbunga. | MMI VIII-IX |
| 1994 Jan 21, Epicentre 1.3ºN - 127.6ºE, Magnitude: 6.8 Mb Depth: 33 km | **Kao-Malifut**: Halmahera - cracking, 500-1000 aftershocks, tsunami, 2 people killed at Makian, Malifut, disaster at village, 365 houses, 8 school buildings, 5 offices, 20 religious buildings damaged. | MMI VII |
| 1994 Feb 16, Epicentre 5.0ºS-104.3ºE, Magnitude: 6.2 Mb Depth: 33 km | **Liwa** : South Sumatera - disaster at Liwa, Way Mengaku, Sukarame, Suoh, Sukabumi, Selipas, Sukau, Hanakau, Gunung Sugih, Sebarus, Kenali, 203 people killed, 1000 people injured, thousands of buildings damaged, crackings 20 km long. | MMI VII-IX |
| 1995 May 20, Epicentre 1.06ºS - 120.25ºE, Magnitude: 5.8 Mb Depth: 30 km | **Parigi**: Central Sulawesi - damages at Torono, Malakosa, Piore, Suli, Toki Balinggi, Torue, 63 people injured, hundreds of buildings damaged. | MMI VI |
| 1995 Oct 7, Epicentre 2.1ºS -101.3ºE, Magnitude: 7.0 Ms Depth: 16 km | **Kerinci**: Jambi - damages at Kerinci district, Gunug Raya, Air Hangat, Sitinjau Laut, Sungai Penuh and Danau Kerinci, 84 people killed, hundreds of people injured, 17,000 houses damaged. | MMI VII |

# V. EARTHQUAKE MONITORING PROGRAMME IN INDONESIA

## 1. INSTITUTIONS RELATED TO DISASTER MANAGEMENT IN INDONESIA

The disaster can hamper and disrupt both human life as well as the realization and the result of development. So it is necessary that the disaster management should be planned correctly and perfectly carried out, and well co-ordinated and integrated. To guarantee the smoothness of the implementation in the disaster management operation it is necessary to form coordinating institutions.

**a. National Level**

*(1) Institution*

To cope with disaster at central level is a non-structural institution that is called the National Coordinating Agency for Disaster Management (BAKORNAS-PB = Badan Koordinasi Nasional Penanggulangan Bencana), which is responsible to the President of Indonesia. The Coordinating Agency for Disaster Management is chaired by the Minister Coordinnator for People's Welfare.

*(2) Membership*

Membership of the National Co-ordinating Agency for Disaster Management consists of:

* The Minister Co-ordinator for People's Welfare as Chairman concurrently member;
* The Minister of Social Affairs;
* The Minister of Home Affairs;
* The Minister of Health;
* The Minister of Public Works;
* The Minister of Communication;
* The Governor, Head of the Provincial Region;
* The Commander-in-Chief of the Armed Forces; and
* The Director General for Social Assistance Development, Department of Social Affairs, as Secretary concurrently member.

*(3) Co-opted Membership*

Heads and officials of other related Departments and Non-Governmental Organizations as co-opted members, i.e. :

* The Department of Defence and Security;
* The Department of Mines and Energy;
* The Department of Tourism, Post and Telecommunication;

* The Department of Trade and Industry;
* The Department of Agriculture;
* The Department of Forestry;
* The Ministry of the State Minister of Environment;
* The Agency for the Assessment and Application of Technology;
* The National Atomic Energy Agency;
* The National Aviation and Aerospace Institute; and
* The National Co-ordinating Agency for Surveys and Mapping.

Related Non-Governmental Organizations, i.e. :

* The Indonesian Red Cross;
* The Civil Defence;
* The Boy Scouts and Girl Guides; etc.

*(4) Secretary*

The Director General of Social Assistance Development, Department of Social Affairs is Secratary concurrently member. In performing his duties the Secretary is assisted by a Deputy Secretary, who leads the Secretariat.

The Secretariat has the function of a center of co-ordination, planning, controlling, monitoring and evaluating and as a Clearing House. It is called the Indonesian Disaster Management Center (IDMC).

*(5) Working Groups*

In the implementation of duties the Chairman of BAKOSNAS-PB would organize working groups in accordance with the existing requirements. Each working group is lead by the Sectretary of BAKOSNAS-PB. Formation, assignment in details and work procedures are stipulated by the Chairman of BAKORNAS-PB.

Each working group is lead by the respective Chairman and co-ordinated by the Secretary of the National Coordinating Agency for Disaster Management.

**b. Provincial Level**

The Provincial Government and related provincial government agencies connected to the disaster management become the extention of the National Co-ordinating Agency for Disaster Management organization in the provincial region. In performing his function, this co-ordination for disaster management is built in the organization of the provincial government, assisted by the Armed Forces and other agencies in the provincial regions, relevant to their own functions.

**c. Executing Units**

*(1) Institution*

It is a non-structural institution to cope with disaster in the district or municipal level that is the Executing Unit of Disaster Management, which is responsible to the Chairman of the National Co-ordinating Agency for Disaster Management and the Governor, Head of the Provincial Region.

*(2) Membership*

Membership of the Executing Unit of Disaster Management consists of :

* Head of District or Major as Chief concurrently member;
* Commander of Military District as First Deputy Chief concurrently member;
* Head of Police Resort as Second Deputy Chief concurrently member;
* The Regional Secretary of District or Municipal Region as Secretary concurrently member;
* Chief of Civil Defence of District or Municipal Headquarters as member;
* Head of the Regional Offices of the related Departments and other related officials in the District or Municipal Headquarters as members;
* The related community organizations and other organizations as co-opted members.

**d. Disaster Management Task Forces**

The Disaster Management Task Forces are the organizations developed to cope with disasters in the Sub-District level or in particular areas. Each Disaster Management Task Force has a Chief, Deputy Chief, Secretary and members with their job descriptions and responsibilities stated in the decision made by the Head of District or Major in his capacity as the Chief of the Executing Unit of the Disaster Management.

## 2. NATIONAL SEISMIC MONITORING NETWORK

To locate seismic epicenter and its magnitude, the seismologists require seismic data from the seismic stations. The quantity and quality of the data determine the accuracy of the epicenter's location. The quantity of data means the number of time arrival of seismic phase used in the determination, while the quality means the clock's precision used, the distribution of the station with respect to the epicenter and the exact pointing out of the seismic phase (this will depend on the signal to noise ratio of the signal).

**a. History of earthquake monitoring system in Indonesia**

The Meteorological and Geophysical Agency (BMG = Badan Meteorologi dan Geofisika) started to operate permanent seismic station in 1908 by installing Wiechert seismograph horizontal component in Jakarta. The vertical component of the seismograph was installed later in 1928 at the same site. The operation seismic network began in the decade of 1960 by operating 10 photographic electromagnetic seismographs in ten

Fig. 7 Map of Seismograph Network in Indonesia geophysical stations, namely: Medan, Jakarta, Tangerang, Lembang, Denpasar, Ujungpandang, Manado, Kupang, Ambon and Jayapura. Most stations were equipped with 3 component seismometers, which consisted of one SP vertical and LP horizontals. Due to the negative cost-benefit ratio in operating this type of seismograph, the operation was stopped in 1991.

Beginning in the middle of the decade of 1970, initiated by the programme of Seismological Network in Southeast Asia, sponsored by UNESCO, the BMG has expanded its seismic network by operating 30 seismic stations (Figure 7). The stations are operating one vertical seismic sensor SP and recorded on visual heliocorder. At some stations the equipment has been upgraded to three SP sensors.

On regular basis, the data are reported every 3 hours and sent to the Regional Center and National Center via GTS of Indonesia, together with the meteorological data.

In specific cases, such as a significant earthquake, the seismic data are sent or requested in an emergency mode via telephone or facsimile. It should be noted that this kind of communication is not always in good condition. On the real operation, this kind of operation faces a lot of obstacles.

**b. Telemetered seismograph network**

At present the BMG is also operating telemetered seismic network, which consists of 32 sensors that are grouped into five regional networks. The selection of the five centers is, in fact, in accordance with the BMG regional structure, i.e. :

| **Regional Network** | **Number of Stations** | **Regional Center** |
|---|---|---|
| North Sumatera | 8 stations | Medan |
| West Java | 6 stations | Ciputat, Jakarta |
| Bali | 8 stations | Denpasar |
| South Sulawesi | 2 stations | Ujungpandang |
| Irian Jaya | 3 stations | Jayapura |

*(1) Regional Networks (Figs. 8-12)*

The number of seismic sensors at each regional network is not the same. This is mainly due to availability of finances to the establishment. Most of the sites are located in the areas which are not very easy to reach except at the Regional Network III in Bali and surroundings. This condition was forced by two requirements for obtaining a good site, that is from geological point of view and the need of line of sight for radio link communications. The seismometer has dual output for high and low gains in order to increase its dynamic range. The seismic signals from the sensors are sent to the Regional Seismic Center using UHF radio link.

Fig. 8    Sumatera Seismic Network

Fig. 9 West Java Seismic Network

Fig. 10 Bali Seismic Network

Fig. 11 South Sulawesi Network

Fig. 12 Irian Jaya Network

At the Regional Seismic Center the seismic signals are then recorded analogically on graphic recorder, while the digital record is on event triggered basis.

Four selected signals in digital form with 50 samples/sec and 12 bits are sent to National Seismological Center (NSC) at BMG Headquarters, Jakarta, via leased channel of the State Telecommunication Company, using medium speed of 4800 bps.

The processing facility at the Regional Center for the time being is still limited. It means that the seismologists should analyze the seismogram manually and then they do data entry for processing the event, while the digital data should be sent to the NSC to be processed every 2-3 weeks.

*(2) National Seismic Center*

Started in early 1996, the NSC is equipped with a new system, namely, ARTDAS and XIDAS, which is operated on Sun work stations. The system can receive the seismic signals directly from RSC on real time basis.

The incoming seismic signals from 5 regional centers, at which 4 channels of 4 seismic sensors are received by the system called PAC. The data received by PAC is n the form of data blocks. After phasing the data blocks coming from regional centers, digital samples are sent to the ADC to be recorded afterwards on graphical recorder. The PAC itself is synchronized by a clock which is regularly synchronized by GPS time receiver. Eight of the 20 signals received by PAC are sent to a strong earthquake alarm system which will give alert when it detects an earthquake with local magnitude greater than 4 RS. The PAC system also sends the digital data to the ARTDAS system.

The other institution implementing seismic investigations is the Geological Research and Development Center (GRDC). Within the framework of BAKORNAS-PB, the GRDC administratively lies under the Ministry of Mines and Energy.

The activities of GRDC are more practical, by combining epicenter locations from historical data from BMG and other sources with geological condition in which earthquake repeatedly occured, the GRDC now has been working on earthquake monitoring and mitigating their effects. The current work is to collect all historical earthquake data available from several sources, to delineate the earthquake prone areas, measuring potential seismic hazards in an area and mitigate the effect of seismic activity in an area. Several potentially seismic hazardous areas have been identified and comunicated to other government agencies, such as the Ministry of Public Works and the Ministry of Social Welfare.

## 3. SEISMOTECTONIC RESEARCH

The Indonesian region is one of the most seismically active zones of the earth; at the same time it has a leading position from the point of view of active and potentially active volcanoes. It is a typical island-arc structure with its characteristic physiographic features, such as a deep oceanic trench, a geanticline belt, a volcanic inner arc and a marginal basin.

Fig. 13 Seismotectonic Map of Indonesia

In most subduction zones, motion of the subducted plate is nearly perpendicular to the trench axis. In some cases, for example Sumatera, where the motion is oblique to the axis, a strike-slip fault zone is seen, and is lying parallel to the volcanic chain.

In the subduction zone southwest of Sumatera, the Sunda trench axis strikes approximately N37$^o$W. The Indian Ocean crust is moving in an azimuth of approximately N23$^o$E relative to SE Asia, giving an angle of obliquity of 60$^o$. Eastern Indonesia, forming the southeastern extremely of the SE Asian lithospheric plate, crushed between the northward-moving Indo-Australian and the westward-moving Pacific plate, is certainly the most complex active tectonic zone on earth. The rate of subdudction is some centimetres per year; for example, it is 6.0 cm per year in the West Java Trench at 0$^o$S 97$^o$S (azimuth, 23$^o$); cm per year in the East Java Trench at 12$^o$ S 120$^o$ E (azimuth, 19$^o$) and 10.7 cm per year in New Guinea at 3$^o$S 142$^o$E (azimuth, 75$^o$). Figure 13 shows seismotectonic map of Indonesia.

Frequent volcanic eruptions and frequent earthquake shocks testify to the active tectonic processes which are currently in progress in response to the continued movement of these major plates. The distribution of small ocean basins, continental fragments, remnants of ancient magmatic arcs and numerous subduction complexes which make up the Indonesian region indicate that the past history of the region was equally tectonically active.

The purpose here is to contribute to the knowledge of the seismotectonics of Indonesia and to identify those aspects of the seismology and geotectonics which should be the subject of future rresearch.

In more practical sense, earthquake monitoring is conducted by Geological Research and Development Center, where a section, Seismotectonic Section, has the task of conducting earthquake research in Indonesia, with the objective to delineate the seismic hazard area in relation to the geological aspects leading to the mitigation of the earthquake effects in particular regions. The current activities of GRDC are described below.

**a. Research Activities**

*(1) Building a Database of Historical Earthquake Data*

GRDC is collecting historical earthquake data and focal mechanism solution from several sources such as Meteorological and Geophysical Agency (BMG, Indonesia), United States Geological Survey (USGS, USA), Earthquake Research Institute (ERI, Japan) and also, some time, from French institutions. Currently in GRDC historical earthquake data is available beginning from 1900 until 1995. All information is collected via facsimile and electronic mail.

*(2) Neotectonic and Active Fault Study*

Neotectonic study is to observe quaternary structural geology that develops in an area and its possibility to generate an earthquake shaking. This study is using airphotographs image to localized neotectonic figures and ground checking to relate to the image available on the photo.

Study on active faults, using mobile temporary networking seismographs instalation to measure microseismic events, combined with a local network of Global Positioning System (GPS),which enable to measure the changing of position. Both measurements (seismographs and GPS), are run repeatedly at a certain time in the same location providing active fault dimension and kinematic behaviour. The data is useful to delineate earthquake prone area and can be used by civil engineers to design building codes.

At present two large Global Positioning Networks in Sumatera have been installed. The installation was done in 1991 and remeasurement of the instalaltion was conducted recently and the calculation is being done. Another GPS geodynamic study was also installed in Sulawesi, and 8 points were installed here, covering all of Sulawesi island.

The data of the GPS measurements provide the knowledge of slip vector of the fault, which is useful in calculating probabilistic maximum magnitude and return period of the region.

*(3) Study on Ground Motions*

This study is still premature at GRDC. A pilot study was conducted in Gorontalo area, producing a probabilistic earthquake occurrence in the area for specific site conditions and several recurrence times (Figure 14 a, b).

This study is using selected earthquake database catalogue collected from broad band seismic stations, adopted from USGS monthly reports . The software used is SEISRISK III, applying analogy of Fukushima and Tanaka ground motion attenuation equation (1990) for Japan area, computer analysis resulting a probabilistic ground motion map of particular site response in an area.

In another area, this study was started in Sumatera and segmentation of the Great Sumatera Fault Zones. According to the data available, such as satellite image, airphotos and historical seismicity combined with the data of damaging earthquakes in Sumatera, the Great Sumatera Fault Zones can be segmented into at least 11 segments.

*(4) Study on Liquefaction*

The objective of this study is to localize the area that potentially has a liquefaction when an earthquake jolted.

Several earthquake events show that liquefaction occured following earthquake shaking, such as Blangkejeren earthquake of 1991, Flores earthquake of 1992 and Liwa earthquake of 1994.

The site geological conditions, such as alluvium deposits of former river channel and flooding plain, deltaic deposits, area of reclamations and beach sand deposits, the characteristics of the liquefied lithology, in particular grain size in water saturated condition, are important aspects. The liquefied area is important to know because it can cause damage to the buildings that lie over this kind of lithology.

*(5) Tsunami*

The tsunami is the direct effect of an earthquake event and occurs when the epicenter of earthquake lies beneath sea. The thrust fault is the biggest tsunami generator compared with any other fault type. A bigger thrust fault generates a more powerful tsunami . Indonesia has also a lot of experience in tsunami attack. In the last 97 years (1899-1995), 48 tsunami related to the tectonic quakes have occurred here (Figure 15).

Based on historical tsunami record, it is revealed that the shores of North Aceh, West Sumatera, Nias Island, Sunda Strait, Cilacap, Souteast Java, Bali, West Nusatenggara, Maluku Islands, Ambon, Seram, Halamhera, Yapen region, Sulawesi, Kalimantan are prone to be attacked by the tsunami.

*(6) Landslides*

Commonly landsliding is controlled by rugged terrain and high rainfall intensity. Some landslides occurred by triggering of earthquake shaking. In general, the landslides are controlled by several factors, such as topography, rock conditions (fracturing, structure and stratigraphy), rainfall intensity, vegetation cover, land use and earthquake (shaking). In Indonesia these factors have been dominant. In mountainous regions such as volcanic land covered by loose material, and associated debris, avalanches commonly occur. This more frequently takes place in rainy season. High density of earthquakes at plate boundaries and active faults have also magnified occurrences of landslides.

The area susceptible to landslides in Indonesia is located along the Sumatera's Barisan Mountain range, volcanic terrain in Java, almost the whole area of islands of Nusatenggara, and in Jaya Wijaya mountain range in Irian Jaya.

In the last ten years a total of 1,663 casualties were caused by landslides. In the period 1980-1990, twenty landslides of various degrees have occurred.

The institution responsible for landsliding studies is the Directorate of Environmental Geology which, like GRDC, lies under the Ministry of Mines and Energy.

Fig. 14a

Fig. 14b

Fig. 15　Map of Tsunami Region in Indonesia

**b. Seismotectonic Maps**

Some maps produced by the GRDC in relation to earthquake study are listed below :

| No. | Seismotectonic Map Title | Scale | Publication Progress |
|---|---|---|---|
| 1 | Seismotectonic Map of Indonesia | 1 : 5,000,000 | Published |
| 2 | Seismotectonic Map of Tarutung Area, North Sumatera | 1 : 250,000 | Published |
| 3 | Seismotectonic Map of Blangkejeren, Aceh | 1 : 250,000 | Published |
| 4 | Seismotectonic Map of Majalengka Area, West Java | 1 : 250,000 | Under print |
| 5 | Seismotectonic Map of Lampung Area, South Sumatera | 1 : 250,000 | Under print |
| 6 | Seismotectonic Map of Alor Area, Nusa Tenggara | 1 : 250,000 | Under print |
| 7 | Seismotectonic Map of Palu Area, Central Sulawesi | 1 : 250,000 | Under print |
| 8 | Seismotectonic Map of Gorontalo Area, North Sulawesi | 1 : 250,000 | Under print |
| 9 | Seismotectonic Map of Liwa Area, South Sumatera | 1 : 250,000 | Under print |
| 10 | Seismotectonic Map of Tanjungkarang Area, South Sumatera | 1 : 250,000 | Under print |
| 11 | Seismotectonic Map of Bantarkawung Area, Central Java | 1 : 250,000 | Under print |
| 12 | Seismotectonic Map of Flores Area, Nusatenggara | 1 : 250,000 | Open file report |
| 13 | Seismotectonic Map of Halmahera Area, Maluku | 1 : 250,000 | Open file report |

Seismic hazard assessment is quite premature in the country, thus development in this field of study is urgently required. Data collection on localizing epicenters is not enough. The interdisciplinary geological, seismological and geophysical investigations are required to construct probabilistic seismic ground motion maps with respect to the frequency of occurrence of earthquakes in a particular area.

**c. Seismotectonic Significance**

***(1) Sumatera***

Katili (1981) suggested that the oldest rocks known are of Permo-Carboniferous age. During this time the area was occupied by an elongated sea-basin, in which a thick sequence of bathyal and neritic sediments was deposited, and at the same time volcanic activity started in the area. The extrusion of andesitic lavas continued until late Permian.

At the beginning of Triassic time, volcanic activity became very weak and during the late Triassic came to a complete standstill. Sedimentation continued undisturbed into the Triassic. An introductory phase to the later orogenic movement may have started immediately after Triassic time (possibly in the Jurassic), with the intrusion which can now be found in sills and dykes in the Triassic deposits.

The main phase of folding took place in the Middle Cretaceous when the complete sequence of pre-Tertiary pelitic rocks was thrown into mainly isoclinal folds. This folding was accompanied by emplacement of granitic and granodiorite rocks, changing the pelitic rocks and volcanic tufs adjacent to the contacts into gneisses.

After an uplift in late Cretaceous time the area was strongly attacked by erosion and a considerable thickness of sediments disappeared. Few Jurassic or Cretaceous deposits survive in Sumatera. It is quite possible that a part of the area had already risen above sea level shortly after the deposition of the Triassic rocks.

The Eocene was a period of denudation of the Barisan mountain system, which, as has been stated earlier, was folded during late Cretaceous time (Proto-Barisan). Due to tensional forces acting on top of the Proto-Barisan geanticlinal system, a longitudinal graben (Sumatera fault zone) came into being along the entire length of Sumatera. During the Oligocene, the Proto-Barisan range disappeared slowly below sea level. In several places, but particularly in the south of the Proto-Barisan range, volcanic activity started.

In Middle Miocene time the Barisan geanticline was uplifted for the second time. In the fore-deep, which was situated in the present non-volcanic outer arc, folding and thrusting took place simultaneously, affecting the Early to Middle Tertiary sediments. It is remarkable that the sediments in the subsiding trough of eastern Sumatera (East Sumateran Basin), on the other side of the Barisan Ridge, were hardly affected by this intra-Miocene orogenesis. In the East Sumateran Basin, sedimentation continued from Oligo-Miocene to Quaternary times.

The Pleistocene period in Indonesia was characterized by powerful moutain-building. In some areas the orogenic movements started in Pliocene time and in many parts continued into Holocene and recent times. In Lower Pleistocene time or probably earlier, horizontal movements of a dextral character commenced along the entire length of Sumatera, affecting the combined Mesozoic and Miocene fold systems and the existing graben structure. The same tectonic conditions which produced the wrench-faults were also responsible for the moderate folding of the East Sumateran Basin.

**Seismicity**

Shallow seismicity prevails within the axis of the trench and the volcanic belt; shallow, plus intermediate, seismicity touches the line of volcanoes. Disregarding these two particular cases as well as the Krakatau region, the volcanic chain in general is almost perfectly aseismic, which corresponds well to the explanation given in the previous section. No deep seismicity is present in Sumatera. This suggests that the penetration of the oceanic lithosphere in the area west of the Sunda Strait, that is, on the island of Sumatera, by no means exceeds km measured vertically from the surface.

The pattern here (Bengkulu area and adjacent area) is again very simple. A large shock of M = 8.1 is known near the plate boundary, but a little oceanward of it, that created an active centre with a maximum value of $23,610^{10}$ erg $^{0.5}$ (Hedervari and Papp, 1981).

The Krakatau area appears to be one of the most important regions within the middle Indonesian arc. Hedervari and Papp (1980) suggested that no fewer than four very powerful earthquakes took place on the two opposite sides of the Sunda Strait, very near

Krakatau (M = 7.0 and m = 7.5 for which h, the focal depth, was less than 70 km; one shock with Mm = 7.0, h = 80 km and another one with M = 7.2, h = 75 km). In addition to these, southeast of Krakatau, Hedervari & Papp know of two very deep shocks (M = 7.5, h = 600 km and M = 7.1, h = 600 km). They suggest the concentration of so many strong earthquakes, and particularly the four on the two opposite sides of the Sunda Strait, very near the extraordinarily active volcano of Krakatau (Anak Krakatau) indicates that the Sunda Strait is undergoing great tectonic stresses which are related to the clockwise rotation of Sumatera, and which are reflected both in the present-day seismicity and the very vigorous volcanism.

Huchon & Le Pichon (1984) propose that the northwestward motion of the southwest Sumatera block along the Sumatera fault zone, away from the northeast Sumatera and West Java blocks, has resulted in the formation of the Sunda Strait by extension.

*(2)* ***Java***

The modern structural belts of onshore and offshore Sumatera trend southeastward and inflect abrupty to eastward between Sumatera and Java. The major morphostructural units can be recognized along the margin of Java. However, the outer arc ridge, interpreted as the summit of the accretionary prism, is developped off Java. The westernmost part of Java Island, called the Banten block, belongs, geologically speaking, to Sumatera. Based on a reconnaissance survey made by Huchon on the west coast of West Java, it seems that little deformation occurred in this area, except uplift.

Java presents many contrasts with Sumatera. The accretionary prism is less developed off Java than off Sumatera, where the sedimentary influx coming from the Bengal deep-sea fan is greater. The young volcanic rocks are markedly more mafic in average composition than are those of Sumatera. The basement formation within the Java area consists of various igneous and metamorphic rocks. The basement complex has been rigitified since the end of the Cretaceous. This orogenesis has furthermore accentuated metamorphism, folding and faulting.

At the beginning of the Tertiary, block faulting with differential subsidence took place which thus gave its topographical appearance to the pre-Tertiary basement. These movements continued until the mid-Miocene which was then dying out. In Plio-Pleistocene time the main folding phase took place which mainly affected the younger Tertiary formations. The basement rocks of Java that are exposed consist of a melange of Late Cretaceous or very Early Tertiary age. No indication of old continental crust exists.

Melange that involves Upper Cretaceous and Palaeocene sediments is exposed in three small areas south of the mid-line of Java, namely: the Lok Ulo area, the Jiwo Hills, Central Java, and Ciletuh in the southwest corner Java (West Java). The Lok Ulo melange complex is exposed beneath a folded cover of shallow water and continental sediments, dated roughly within the Eocene.

A large mass of polymict melange is thrust over coherently deformed sedimentary rocks. The quartz porphyry, anomalous here in a melange terrain, may owe its presence to melting caused by subduction beneath the wedge of the very young hot Indian Ocean.

The Jiwo Hills melange consists of varied green schist, amphibolite, phyllite, slate, quartzite, limestone, radiolarian limestone, radiolarian chert, and serpentine, all contorted and highly sheared. Overlying strata are middle and upper Eocene marls and limestone.

The Ciletuh melange consists of schist, phyllite, periodite, gabbro and basalt, all variously altered and sheared. Deformed upper Eocene and younger clastic rocks overlie these crystalline rocks.

Palaeogene sedimentary rocks are exposed in small areas on top of these melange terrains and elsewhere near the south edge of the modern volcanic belt, in southwestern and southcentral Java. An arc of Eocene and Oligocene volcanic islands is widely assumed to have been present in medial or southern Java. The volcanic rocks or submarine volcanic rocks assigned to the Paleogene by the early mappers are the "Old Andesites".

The belt of active calc-alkalic volcanoes is superimposed upon older volcanic and volcaniclastic rocks, which are intercalated with Oligocene and Neogene sediments and are intruded by small plutonic masses of similar composition. The main magmatic belt lay in about its present position during most of Miocene and Pliocene time, but during the late Oligocene and Early Miocene it lay closer to what is now the south coast.

*(3)* ***Kalimantan***

The pre-Late Triassic sedimentary rocks in Kalimantan were deposited in a fore-arc environment and a volcanic facies has been recognized in west Kalimantan consisting of intensely altered basic effusives, associated with cherts. This association suggests the existence of an arc facing north during the Carboniferous-Permian.

In Palawan, in the southern Philippines, basement rocks consist of highly deformed Permian sediments and volcanic intruded by Creetaceous granitic rocks. Presumably these basement rocks were derived from Indo-China or from South China and, as a volcanic arc existed in Permo-Carboniferous time in Kalimantan. These basement rocks of Palawan are not related to the rocks of similar age in Kalimantan.

Hartono (1984) suggested that Kalimantan is assumed to lie on the eastward extension of the Bentong Raub suture from Peninsular Malaysia through Biliton. As in Peninsular Malaysia, the collision in Kalimantan is not as prominent as in Thailand; moreover, in South Kalimantan the collision zone is buried beneath a tectonic super structure.

Hamilton (1978, 1979) interpreted the widely distributed ophiolites and associated rocks in east Kalimantan as melange resulting from subduction of oceanic crust from the east. This melange is associated with silicic volcanic and granitic rocks in southwest Kalimantan which probably formed an island arc. The granitic intrusions assisted the cratonization process in Kalimantan.

Haile (1981), from palaeomagnetic and radiometric data, concluded that west Kalimantan and the Malay Peninsula have behaved as a craton since Cretaceous time. Kalimantan has rotated 50° anti-clockwise, so that at its inception the arc was less curved than it is now.

Extensional tectonics off Indo-China and South China moved the oceanic crust southward to be subducted under Kalimantan. This process started in the Early Tertiary and ceased before the Pliocene in Kalimantan, but continues at present in the Manila Trench. It is manifested in Kalimantan by Eocene melange and accompanying fore-arc sediments. During the Neogene, fore-arc sediments were deposited in Serawak and also intermediate and basic volcanic rocks were erupted in the interior of Kalimantan.

Almost the whole of Kalimantan is aseismic - this is a cratonic area - except the northeast coast of the island where a sole shallow shock of M = 7.0 took place and, therefore, a small active centre came into being.

*(4) **Sulawesi***

Sulawesi and its surroundings consists of three main tectonic units, namely, the eastern arc or province, which is characterized by thrust tectonic associated with the emplacement of an ophiolite-metamorphic suite; the western arc or province, which displays normal folding in a sequence of Mesozoic to Tertiary metamorphics, sediments and volcanics intruded by plutonic rocks of acid and intermediate composition; and the Banggai-Sula Province which is characterized by a basement complex of Carboniferous metamorphic and Permo-Triassic plutonic rocks, overlain by a Mesozoic continental-derived sedimentary succession containing ammonites, belemnites and pelecypods.

Southwest Sulawesi is located at the southern end of the latter arc. It can be divided into two north-trending mountain chains, called the Western Divide Mountains and Bone Mountains. These converge in the southern tip of the peninsula and form there a mountain landscape, dominated by the inactive Lompobatang Volcano. The area between both mountain chains is occupied by the Valley of the Welanae River, a graben-like structure that is known as the Walanae or Central depression. This structure forms part of a major N to NW trending fault zone. In the north a marked depression filled with Quaternary sediments extends from the mouth of the Sungai (River) Sadang on the west coast, through Danau Tempe and the Neogene Singkang basin to the east coast. This depression appears structurally to separate southwest Sulawesi from the rest of the western arc. In the Sadang River area, the structure lineament is known as the Sadang fault zone.

The relation of the eastern to the western part of Sulawesi has been the subject of speculation, because the geology of the eastern part differs greatly from that of the west. Palaeomagnetic results from Jurassic to Early Cretaceous radiolarian cherts in the southwest arm indicate that these cherts formed within 3° of the equator, and that SW Sulawesi then lay close to its present position relative to west Kalimantan and the Malay Peninsula, and that these three areas probably formed part of the same plate, which has rotated some 30° to 40° anticlockwise since the Jurassic (Haile, 1978). Similar cherts were sampled from one exposure in the east arm, and the direction of magnetization shows an inclination relative to the bedding plane equivalent to a paleo-latitude of 42, consistent with a derivation of the east arm from higher latitudes than the southwest arm derives from. Results from the Late Cretaceous of northwest central Sulawesi (Sasajima et al., 1978; Sasajima, 1980) show 14° anticlockwise rotation, with inclinations of 32°, equivalent to a paleo-latitude 16° of present; Sasajima's sites are east of the Palu fault, along which east Sulawesi may have moved north, which could explain the discrepancy in inclination between this site and the Jurassic - Early Cretaceous site of Haile.

Four sites in Tertiary igneous rock (two of sills, one of tuf, one of lava), believed to be late Cainozoic, give a mean direction near that of the present field or along this direction but in a reversed sense, indicating that the southwest arm was complete by the time these rocks formed.

**Tectonic Development**

The tectonic development of the western and eastern Sulawesi Provinces is closely related to the tectonic development of the Banggai-Sula Province. During the late Cretaceous, a thick sequence of flysch-type sediments was deposited in broad areas along the western Sulawesi Province.

The flysch-type sediments are unconformably underlain by the melange complex basement in the south part and by a metamorphic complex basement in the central and north episode uplifted and thrust most of the material within the eastern Sulawesi Province. The metamorphic rocks were thrust westward into the western Sulawesi Province; likewise, the ophiolite rocks were also thrust and imbricated with associated rocks possibly including the melange, but in the opposite direction, namey eastwards into the Mesozoic and Paleogene sediments of the Banggai-Sula Province.

During the uplifting of the whole region of Sulawesi, which commenced from the Middle Miocene, block faulting was initiated in various places to form graben-like basins. In Pliocene time the whole region was subjected to block faulting and the major fault, and the subsequent movement, initiated the present morphology of Sulawesi island. This tectonic event produced a shallow and narrow marine basin in some parts of the region and some isolated basins island. Coarse clastic rocks were deposited in these basins and formed the so-called Sulawesi molasse.

The Middle Miocene tectonic event also bent the western Sulawesi Province into present curved form and exposed the metamorphics within the neck of the island.

**Seismicity**

Seismicity in the eastern arc and in the Banggai-Sula Province is much less intense than that beneath the Molluca Sea. The earthquakes recorded in these areas occurred in a narrow zone at shallow and intermediate depths beneath the eastern half of the Gorontalo Basin. These earthquakes define a north-dipping zone which apparently shallows towards the east arm of Sulawesi from a maximum depth of about 180 km at the equator (McCaffrey et al., 1983). The top of the zone of hypocenters appears to dip away from the east arm at about 25°, becoming vertical at depths greater than 60 km. In general, the distribution of earthquakes from the local survey is similar to teleseismic locations (Cardwell et al., 1980), with the significant exxception of the appearance of shallowing towards the east arm.

In the light of the ambiguity surrounding the relation between the shallow earthquakes beneath the east arm and the intermediate-depth activity beneath the central Gorontalo Basin, McCaffrey and Silver (1980) propose two interpretations. The first is that the two zones are unrelated and the appearance of continuity between them is fortuitious. In this case the shallow seismicity to the south may be due to deformation related to the collision of the Baggai Islands with the east arm and the deeper activity occurs within the southern edge of the Molucca Sea plate thrust-ing westward the north arm and the Sangihe Island arc.

The second, and perhaps more interesting, interpretation is that the zone of seismicity seen in the local survey data dipping to the north from east arm occurs within a single slab of lithosphere connecting the Baggai Islands block to the Molucca Sea plate. The projection of the trend defined by the earthquake foci intersects the surface of the earth in the central part of the Poh Head region of the east arm of the Batui thrust. The Batui thrust has been observed in the east arm and offshore in reflection profiles by Silver (1981) and interpreted as being the site of the underthrusting of the Banggai Islands block beneath the east arm ophiolite and southern Gorontalo Basin crust.

The obvious inference is then drawn that the possibly continuous slab dipping to the north beneath the Gorontalo Basin was once the leading edge of the Banggai-Sula Islands complex and was subducted beneath the east arm and the Gorontalo Basin prior to the arrival of the Banggai Islands into the trench system.

*(5)* ***Talaud***

Silver and Moore (1978) have already described the structural contacts between the deformed rocks of the Molucca Sea and the volcanic aprons of the Halmahera and Sangihe arcs. The contacts appear along the troughs adjacent to the volcanic arcs. Most of the seismic reflection profiles across the troughs indicate thrust contacts where deformed rocks are thrust on to the volca-nic aprons. The deformed rocks in the east thrust on to the Halmahera arc whereas in the west they are thrust onto the Sangihe arc. The reflection profiles between thrust contacts in the Molucca Sea show virtually no structural resolution within the Talaud-Tifore ridge. Judging from the exposures on the islands along the Talaud-Tifore ridge and rocks dredged from submarine ridge, it has been interpreted that the acoustically irresolvable terrain probably consists of tectonic melange.

This tectonic melange is composed of highly deformed material of low average density (2.2 - 2.4 gm/cc) and sound velocity (3.5 km/s) and is thrusting over the adjacent arcs along the east Sangihe and Halmahera thrust (Silver, 1981; Silver et al 1983).

An oceanic microplate, which Sukamto (1979) proposes to call the Molucca microplate, has been present in the Molucca Sea since Middle Tertiary time, possibly Oligocene, bounded by approximately northward trending arc - trench system. This microplate was subducted westward and subsequently produced the Sangihe volcanic arc along the extensional fractures within the upwards bending plate above the subduction zone. The Sangihe is a part of the plutono-volcanic arc of western Sulawesi Province where a strong volcanism is indicated by wide distribution of Miocene-Pliocene volcanics.

Possibly volcanism in the Sangihe arc started in Late Oligocene time. From the east another microplate that Sukamto (1979) calls the Halmahera micropate, was subducted westward underneath the Molucca microplate and produced the Talaud-Tifore volcanics along the extensional fracture above the subduction zone.

Volcanism in the Talaud-Tifore arc possibly started in the Middle Tertiary as indicated by the andesitic-basaltic volcanics that are stratigraphically older than the Middle Miocene to Pliocene sediments. Melange wedges occurred in the troughs east of the Sangihe arc as well as east of the Talaud-Tifore arc.

Volcanism in the Sangihe arc has continued until the present time, but in the Talaud-Tifore arc it has decreased rapidly since the Middle Miocene and become totally dormant in the Late Pliocene. As the Molucca and Halmahera microplates collided and the subduction process terminated, it is assumed that the active Halmahera microplate was bent upwards. The bending and rupturing of the Halmahera microplate affected the volcanic and melange rocks that occurred in the Talaud-Tifore arc trench system. Squeezing within the melanges and thrusting within the volcanics occurred in this stage, possibly during the Middle Miocene. In the next stage imbricate thrusts occurred at the frontal part of the bending plate. In relation to this encroachment process, part of the oceanic materials and the volcanics broke up into slabs and injected into the melange mass.

The volcanism in the Talaud-Tifore arc was possibly still active in the northern area during the Late to Middle Pliocene as indicated by the occurrence of volcanics on the Miangas and Keratung islands. In the present stage the slabs of ophiolite and volcanic rocks are exposed, together with the melange mass in the Talaud islands.

### *(6) **Timor and the Surrounding Area***

Fitch & Hamilton (1974) proposed that Timor can be regarded as a chaotic complex of imbricated and mainly allochthonous rocks and melange derived from Australia's continental margin during the collision and formation of an outer arc ridge within the subduction zone and the Timor Trough as a shallow subduction trench. Carter et al. (1976) viewed the geology as representing a deformed Australian continental margin, overthrust from the north by several allochthonous units. Chamalaun & Grady (1978) suggested that, prior to a mid-Miocene collision, all the Timor rocks belonged to the Australian continental lithosphere, since in the Late Pliocene to recent uplift of Timor by isostatic rebound.

Johnstone & Bowin (1981) viewed the Kolbano unit, which is found along the south coast of Timor, as ranging from the Cretaceous to Early Pliocene. It is folded recumbently and contains many thrusts and imbricate faults. Carter et al. (1976) interpreted the Kolbano unit as having been scraped from oceanic crust and imbricated into an acretionary prism prior to the continental collision.

The Late Miocene Bobonaro olistostrome is widespread on Timor, having been emplaced by a huge gravity slide that moved from north to south. It consists of exotics within a clay matrix. The exotics, which range from pre-Permian to Late Miocene, have been derived from all the underlying continental rocks on Timor (Carter et al., 1976). Audley-Charles (1975) proposed that the clay was derived from submarine weathering of volcanic ash.

The Viqueque group represents the most recent sedimentary sequence on Timor. It overlies the Bobonaro olistostrome and is Late Miocene to recent. The calcilutite sediments which make up the bulk of this formation suggest a deep water depositional environment during the Late Miocene and Early Pliocene.

During the Late Miocene, the Bobonaro olistostrome began to develop, when Timor tilted sharply to the south in response to the onset of rapid subduction along the eastern end of the Indonesian subduction zone. On the southern edge of this subduction zone, sediments were scraped from descending Cretaceous oceanic crust and incorporated into the olistostrome. For the remainder of the Miocene and the Early Pliocene, almost all the Timor rocks formed part of an outer arc ridge or basin associated with an oceanic subduction zone: the Batu Puti limestone zone as outer-arc basin, outer-arc ridge, or inner-slope basin sediments.

Prior to the mid-Pliocene, the Kolbano unit developed as an accretionary wedge of oceanic sediments at the leading edge of the subduction zone. The Bobonaro olistostrome contains exotics derived from these deep-water sediments, suggesting that olistostrome deposits continued to develop during the Early Pliocene.

The Bouguer gravity field of Timor and regions to the east, as is generally characteristic of the gradient of gravity anomalies, passes into a belt of negative anomalies, whereas to the north it culminates in a strong positive anomaly over the central part of the Banda Sea. To the west of South Timor the complex gravity field indicates that a north-south discontinuity occurs between Sumba and Timor.

Fitch (1972) summarized the seismic evidence for tectonic behaviour in this region. He reported that there is no evidence from focal mechanisms to support the existence of present-day underthrusting along the eastern end of the Sunda Arc, even though a well-developed inclined seismic zone exists beneath the arc in this region. The dip of the seismic plane for deep-focus earthquakes in eastern Indonesia is steeper than that in western Indonesia.

Immediately to the south of Sumba there is sharp break in three well-defined submarine linear morphological features (Nishimura, 1981 ; Nishimuva et al., 1981). The Java ridge and the Bali trough (4 km deep), separating Java ridge from the volcanic islands of Bali, Lombok and Sumbawa, do not continue to the east of Sumba. East of Sumba there is no trench south of the Sunda Arc separating them from Australia and West Irian. The outer Banda Arc islands, east of the Sumba Arc, separated the Australian shelf by the Timor Trough and its easward extensions that descend in that area to a depth of 3 km.

The Sawu Sea separates Timor and Roti in the outer Banda Arc from the volcanic islands of the inner arc.

A pronounced discontinuity in the linear zone of volcanoes is located on an island north of Sumba. This break may be an exten-sion of the strike-slip fault in southwest Sulawesi, plotted by Katili (1970) and Hamilton (1972). The Late Cenozoic origin of these volcanoes suggests that these dextral movements were Quaternary (Audley-Charles, 1975).

The Timor trough is associated with the southern tectonic bound-ary of the Sunda and southern Banda arc portions, respectively, of the Indonesia subduction zone. The Timor trough is some 3 km shallower than the Java trench and as such has been considered by some to be a relatively minor feature. From the top of Timor to the exit of the Timor trough there is an elevation difference of about 5 km (Johnstone & Bowin, 1981).

The Timor trough is associated with a similar type of structural boundary, except that north of the trough the structural complexity is even more difficult to resolve. However, the data suggest that the northern flank of the Timor trough includes both compressional folds and north-dipping thrust planes (Montecchi, 1976; Von der Borch, 1979). The usual form for subduction zones is convex towards the plate that is being subducted, as is the case throughout the Sunda arc. However, the Timor trough and the outer arc are concave towards Australia, whereas the inner volcanic arc is convex (Brouwer, 1947).

The global solution for relative plate motions predicted that the relative motion at the eastern end of the Indonesian subduction zone in the vicinity of Timor is approximately 70 km/m.y. In the Timor region the down-dip length of the seismic zone, as mapped by Cardwell & Isacks (1978), is approximately 800 km, suggesting an average relative plate motion during the last 10 m.y. of about 80 km/m.y.

Johnstone & Bowin (1981) proposed that the model suggests that the Australian continental crust first entered the eastern end of the Indonesian subduction zone approximately 3 m.y. ago or during the mid-Pliocene. The resulting influx of thick, coherent conti-nental margin sediments into the subduction zone initiated a change in the accretion processes - a deformation or tectonic front, separating deformed from undeformed continental margin sediments, moved rapidly up the continental slope.

In accordance with the model of Johnstone & Bowin (1981), the Timor trough coincides with a tectonic boundary separating a wedge of deformed, but autochthonous, continental margin sedi-ments from the depressed margin of Australia.

McCaffrey et al. (1982) suggested that the large microseismic events that occurred south of Pantar Island, with hypocentres at depths of 70-200 km beneath the eastern Sawu Sea, reveal a trend of dipping to the northwest.

The zone of seismicity dipping to the northwest is at an angle of 45° between 70 and 200 km depth and continuing more sparsely to 300 km. At shallower depths, a few better-located events form a zone that appears to flatten out at about 50 km depth beneath Timor.

The seismic events beneath Timor and beneath the region between Timor and the volcanic arc probably result from a variety of crustal and upper mantle stresses. These stresses include those in, and associated with, the subducted oceanic lithosphere and those resulting from compression of the subduction zone (Johnstone & Bowin, 1981).

***(7) Halmahera***

The metamorphic rocks which form the pre-Tertiary basement in the Bacan, Saleh and Tapas islands (Western Halmahera-Obi Province) are considered to be probably the oldest rocks in the region. The ophiolite of the eastern Halmahera-Waigeo Province, overlain by Jurassic-Cretaceous deep-sea sediments is also clearly of this age. No rocks of pre-Tertiary age are known from the Talaud-Tifore Province.

These relations suggest that at the beginning of the Tertiary the western Halmahera-Obi Province constituted a continental block bordered on its eastern side by oceanic crust. It is not known whether this continental fragment was attached to a major continent at that time or not. The presence of ophiolite fragments among the ocean floor sediments on the eastern side of the block may be due to block faulting, with the erosion of ophiolitic material from fault scarps, or it may indicate that convergent tectonics were already operating in this region in pre-Tertiary times with the erosion of imbricated ocean floor material. These problems require further study.

By Palaeogene times the ocean floor had been formed that is now the Talaud-Tifore Province, perhaps as a result of the develop-ment of a marginal sea which separated the western Halmahera-Obi Province from the major continent to which it had previously been attached. On the eastern side of the continental block, extensive flysch deposits were being laid down.

Clasts in the conglomerates within these flysch deposits include ophiolitic fragments, deep-sea red shales, volcanic andesites and basalts, indicating that at this time an imbricate wedge of ophiolitic material and a volcanic arc had been formed as a result of subduction, and ocean-floor and volcanic-arc materials were being eroded to form the flysch deposits. The flysch deposits were presumably laid down in a fore-arc basin or more localized basins within the imbricate wedge.

By Oligo-Miocene time convergent tectonics were well established, with the continuous imbricate of Palaeogene deposits into the imbricate wedge. In eastern Halmahera, imbricate blocks are separated by westward dipping faults, indicating that subduction of the ocean floor was directed towards the west from the Pacific side. The occurrence of extensive andesite and basaltic volcanics in the western Halmahera-Obi Province indicates that subduction was taking place beneath the older continental block with the development of a volcanic arc.

Minor volcanism on Obi, Bacan, Mandioli and Nanusa in Mio-Pliocene time suggests that subduction was less active then. On the order hand, major convergence had commenced further to the west with the westward subduction of the Maluku Sea floor beneath the Sangir arc.

The volcanic chain which extends along the western side of Halmahera indicates that subduction recommenced beneath the island in early Pleistocene time and is still continuing at the present time.

Silver and Moore (1978) suggest that subduction of the western side of the Maluku Sea, commencing in Miocene time beneath the Sangir Arc, was followed in the early Pleistocene by subduction of the eastern side beneath Halmahera. Subduction contined until nearly l000 km of the Maluku Sea Ocean floor had been subducted.

At the present time the tectonic situation shows compressional regimes in the Talaud-Tifore and Halmahera-Weigeo Provinces and an extensional regime in the western Halmahera-Waigeo Province which forms the site of present-day volcanic arc (Sukamto et al., 1981).

**<u>Seismicity of Halmahera Island and Surrounding Areas</u>**

Here an extraordinarily complicated pattern of seismicity occurs. Shallow and shallow-plus-intermediate active centres occur alike. he complexity of this area is emphasized by the fact that we are dealing with two opposite-facing, oblique hypocentre-systems (Benioff zones). "The Sulawesi system displays a relatively conventional seismic zone dipping west-northwest to a depth of 650 km, whereas the Halmahera system dips more gently east-southeast to a depth of about 240 km" (Hatherton and Dickinson, 1969).

It has been found, however, that in this area there are altogether three well-separated regions of intermediate and deep earthquakes. The first lies between Sulawesi and Halmahera, in the northern part of the Molluca Pass, the second between Halmahera and Mindanao and the third one can be found between Mindanao and the coast of north Sulawesi. The deepest earthquakes in the first of these three areas come into being around 200-250 km, measured vertically downward from the surface; the maximum depth of hypocentres in the second region is the same; finally, in the third area, the greatest depths of earthquake-foci can reach 600-650 km. Among these three regions of intermediate and deep rocks one can find a triangle-like area in which there are only shallow earthquakes.Here, at 2°26'N and l27°l5'E, that is, at the south-eastern vortex of the triangle mentioned, one can find a point which is characterized by abnormally high heat flow, namely 5.2l HFV (Lamont-Doherty Geological Observatory, Heat Flow Data).

These geophysical and physiographic facts, including the two oppositely-directed Benioff zones as mentioned above, strongly suggest that the triangle-like feature which includes the "hot spot" as well may be regarded as a small, local spreading centre which is responsible for the development of the three, well-separated areas of intermediate and deep earthquakes and also for the creation of the two volcanic belts, one in front of the other, but having an opposing curvature.

This suspected spreading centre lies at the northern end of a submarine ridge-like feature, the northernmost tip of which carries Talaud Island. This part of the ridge is bounded by the Sangihe through to the west, by the Talaud through to the north-east, by the Morotai basin to the east (the hot spot mentioned lies in this basin) and by the Ternate through to the southeast. It must be mentioned, however, that no trace of the existence of a rift-valley type of feature can be seen on the surface of this ridge and this fact contradicts the suggestion.

In this area there are some minima, where the released tectonic flux is as low as l0.l0 ergs or even smaller. The broad minimum, that has the largest areal extent among all the minima, can be found just west of the suspected local spreading centre but no physical correlation can be suggested between them. It is noteworthy that the existence of the minima is characteristic only for this part of the Indonesian region.

### *(8) **Northern Banda Arc***

During pre-Triassic times Misooi, Buru and Seram were part of the stable continent of the Irian Jaya-Australia continent. During Triassic to Middle Jurassic time presumably break-up and rift-drift occurred between Seram and "Buru-Misool", followed by sedimentation of the continental platform sequence of flysch-type sediments with subordinate limestone. The break-up and rift-drift were perhaps caused by thermal upwarping followed by block faulting. The break-up stage was succeeded probably by sea floor spreading during Middle Jurassic to Early Cretaceous time, as indicated by deep sea sediments, while minor amounts of volcanic rock occurred in Buru as well as in Seram. On Misool Island the break-up stage is indicated by neritic flysch and limestone with minor volcanics. The break-up stage corresponds to the development of the proto-Banda Sea, part of the Indian Ocean, while Seram was probably located near the triple junction of the rift-drift zone.

Break-up ceased in the Early Cretaceous followed by deep open-sea sedimentation up to Eocene time on Buru and East Seram. The Eocene of Misool is characterized by neritic limestone which presumably was deposited on structural highs. The trend of the rift-drift zone between Seram and "Misool-Buru" apears to be in the NE-SW direction, similar to the regional Jurassic rifting in the Banda Sea (Bowin et al., l980).

During Cenozoic time the arc rotated anticlockwise 98° since Late Triassic time, of which 74° occurred since the Late Miocene (Haile, l978, l98l).

Between the Middle Miocene and the present, Seram and Misool-Irian Jaya collided, while oceanic crust subducted underneath Seram. From the Middle Miocene to the Pliocene the subduction was most active and the Benioff zone may have reached a depth of over 200 km, at which granitic magma could be generated, forming the uliazer magmatic belt.

Green et al. (l980) suggested that the Banda arc system grew eastward and the Banda Sea opened because a triple plate junction formed in eastern Java early in the Cenozoic and moved eastward across the Banda Sea region to its present position at at the junction of the Aru trough with the Torera-Aiduna fault system. The Aru and Seram troughs are offset along a section of the Torera-Aiduna fault system and that section is possibly, therefore, an arc-arc transform (Cardwell and Isacks, l978). The fault is in line with a major tectonic boundary in central New Guinea (Irian Jaya) between the central orogenic belt and the Australian craton.

Untung et al. (l984) suggested that the complicated geological structure resulting from the collision of a continent with an oceanic trench system gives rise to large-amplitude gravity features. The main belt of negative anomalies is arcuate, and terminates in the most western portion of Seram.

The mantle depth of l5 km, modelled in the Banda Sea, shows that mantle depths in excess of 3l km are indicated under Seram, Misool, Salawati and Waigeo. The depth-to-mantle under Seram may relate to subduction zones south of this island.

This is again a very complicated area from the point of view of seismicity, particularly the Banda Sea, under which a remarkable conformation of the down-going lithosphere can be deduced on the basis of the distribution of earthquake hypocentres. The broad belt between Australia and the axis of the oceanic trench is completely aseismic, as would be expected from the deduction that this is a cratonic area with great rigidity and without present-day orogenic movements.

According to Papp (l98l) classification, the Banda Sea region falls into Category IV, which is characterized by strong seismic activity and in which, according to his calculation, Mag = 7.2l.

### *(9) **Irian Jaya***

#### *Geological and Geotectonic Evolution of Irian Jaya*

The mainland of Irian Jaya and Papua New Guinea may be subdivided into three east-trending zones, which differ characteristically in stratigraphic, tectonic and magmatic history. A northern oceanic province of ophiolite and island-arc volcanics is separated from a continental provinces with sediments overlying a relatively stable basement by a transition zone with strongly deformed and regionally metamorphosed rocks. The transition zone forms a belt exposed along the north flank of the central range and is separated from the other provinces by major thrust faults and transcurrent faults.

The distribution and contrasting geology of the provinces is the result of interaction between the Australia-India and Pacific plates which probably dates back to the Early Jurassic. Following the cessation of island-arc volcanism in early Miocene time, a major orogeny resulted from the collision of the Australian continent with an island arc overlying the Pacific plate and from continued convergence after collision. Cardwell and Isacks (l978) suggested that Irian Jaya is being subducted beneath the Banda Sea. They maintained that subduction is not continuous around the arc and that the northeastward-directed subduction in the Aru trough is separated from the southward subduction below Seram by a transform fault in the neighbourhood of the Banda Islands.

This relatively simple zoning on the mainland is not easily applied further west in the Bird's Head and Bird's Neck. This region is an amalgamation of widely diverse terrain with oceanic as well as continental affinities and distinct geological histories. The terrains are juxtaposed along futures which are commonly recognized as major faults.

Fault-bounded fragments of ophiolite, Palaeogene island-arc volcanics and post-volcanic sediments were mapped on Waigeo, Batanta, Biak and Yapen islands and in the Losem and Arfatk mountains. These allochthonous blocks fall into the oceanic province and probably made part of an original continuous magmatic belt which was disrupted by transcurrent faulting during Late Micene and Pliocene time.

The central and southern Bird's Head has a basement of folded and regionally metamorphosed Silurian-Devonian turbidites and the western Bird's Neck area is almost certainly also underlain bay a basement of continental affinities. However, each of these terrains is characterized by a unique stratigraphy and history of deformation of the sedimentary cover; Misool Island, Onin and Kumawa peninsulas are also categorized with the continental province.

The rocks of the Tamrau Mountains, the Wandamen Peninsula and the Wondiwoi Mountains in the east Bird's Neck and of the Weyland Mountains and northern Central Range are strongly and complexly deformed by folding and faulting and have been subjected to regional metamorphism.

These terrains are lumped together in the transition zone. Lithostratigraphic units confined to the Sorong and Ransiki fault zone, although not metamorphosed, area also grouped in this zone.

In vivid contrast to Halmahera and the north Sulawesi area, the pattern of seismicity of north Irian Jaya is very simple. A great shock, of M = 8.l, occurred near the plate boundary at the northern extremity of this area and created an active centre with maximum value of $29,5l0^{10}$ $erg^{0.5}$ (Hedervari & Papp, l98l). Two active centres, with relatively high values, are present in the northern part of New Guinea and another shallow one, with only a small maximal value, near the islands of the Aru group. This latter centre is related to the plate boundary. From here towards Australia the area is perfectly aseismic again, corresponding to the evident cratonic character of this part of the region.

# VI. EARTHQUAKE HAZARD VULNERABLE AREAS IN INDONESIA

In the densely populated island of Java the big fast growing cities are Jakarta, Surabaya, Bandung and Semarang.

The cities of Jakarta, Semarang and Surabaya consist of sedimentary rocks of the backarc basin interfingered with volcanic sediments and pyroclastics. The overlying rocks comprise unconsolidated fluviatile deposits.

Historically, the cities of Jakarta, Semarang and Surabaya are situated within a zone having a scale of V - VI MMI, while Bandung is situated in the zone with a scale ranging from VII to VIII.

All these cities are situated between the 250-350 Beniofff contour implying that the hypocenters beneath these cities are 250 to 350 km deep. The distance from the deep sea trenches in the south is about 350 km.

These features seem to suggest that these cities seem not to be vulnerable to earthquake disasters. However, the lesson learned from the big earthquake in Mexico, 1985, possessing magnitude of 8.1 has changed our opinion regarding the safety of these Javanese cities. It is known that the Mexico City earthquake had its epicenter in the subduction zone, the so-called Micoacan gap situated about 300 km west of the city. In Mexico City itself the shocks started with an intensity of about II on the MMI Scale and within 5 minutes increased to VI on the same Scale. The shocks which lasted for about 40 seconds destroyed 80 to 90% of the buildings in the capital city.

The destruction of Mexico City was caused by the response of the rocks underlying the city. The sub-soil could be divided into several zones, the most important ones being the Lake Bed Zone and Hill Zone. These zones consist of highly compressable deposits with clay characterized by high water content. Other deposits comprise volcanic material, alluvium sandy and silty layer. The ground motion of the Lake Bed Zone was amplified 8 to 50 times. These data indicate that the character of the sedimentary deposits underlying big cities should be studied in detail and that the character of ground motion in big cities should be identified with the help of an accelerograph.

Of concern to us is the city of Bandung, since its southern part, where high rises are beginning to appear, consists of big lake deposits. This area has geologically been mapped in detail but not restated yet into a technical geological map. The physical properties and age of the Bandung lake deposits have not been determined nor also the character of the ground motion. Bandung is situated about 300 km from the very active Java subduction zone, similar to the situation in Mexico City where the trench is situated several hundred kilometers to the west of the city.

Also of concern regarding earthquake disaster is the fast growing oil city of Balikpapan in East Kalimantan. Balikpapan is situated in a deltaic deposit characterized by large "inactive" transcurrent fault in the underlying basement. These old faults can be reactivated since they form a continuation of the active Sulawesi fault which came into being by the westward thrust of the Pacific Plate. The occurrence of earthquakes caused by reactivation of old large faults such as in the Indian subcontinent and China should be studied in detail since cities situated in the so-called stable cratons can be hit by earthquakes which can kill thousands even hundreds of thousand of people.

Other cities in Indonesia likely to be hit by big earthquakes are : provincial capital of Banda Aceh and the tourist city of Bukittinggi, both situated along the large Sumatran transcurrent fault zone ; the provincial capital Jayapura and the oil city of Sorong located near the large Sorong transcurrent fault zone ; the provincial city of Palu lying along the Palu-Koro transcurrent fault ; and perhaps the famous city of Denpasar situated in the proximity of the Bali backarc thrust.

For the time being, twenty five areas in Indonesia are classified to be the earthquake hazard vulnerable areas. The studies in these areas are still continuing to complete every aspect needed for mitigation of the earthquake hazards.

25 earthquake vulnerable regions in Indonesia (Figure 16) are :

1. Aceh
2. North Sumatera
3. West Sumatera
4. Bengkulu
5. Lampung
6. Sukabumi
7. Yogyakarta
8. Lasem
9. East Java-Bali
10. Nusatenggara Barat
11. Nusatenggara Timur
12. Aru
13. Mamuju
14. Buton
15. Central Sulawesi
16. North Sulawesi
17. Sangir Talaud
18. North Maluku
19. South Maluku
20. Birdhead of Irian Jaya
21. Jayapura
22. Nabire
23. Wamena
24. East Kalimantan
25. South Kalimantan

Fig. 16

# VII. MITIGATION EFFORT

Recent earthquake events, even in the countries with most sophisticated earthquake reasearch facilities, indicate that scientists failed to warn people in advance of the coming danger. To locate seismic epicenter and its magnitude, the seismologists require seismic data from the seismic stations. The seismic stations covering the Indonesian region are operated by the Bureau of Meteorology and Geophysics. This network is part of the worldwide seismic network.

In seismotectonic study, detailed geological investigation is carried out in earthquake prone areas. Microtremor study is aimed at understanding the focal mechanism and also at analyzing the potential accumulation of energy in the fault segment, leading to the forecasting of the probable occurrence of earthquakes in the fault zone. A seismic hazard zoning map is prepared based on the geological conditions and the baseline data of the recorder earthquake occurrence. The map is used for regional development planning.

The mechanism of generation of earthquakes in time, place and magnitude, which lies at the core of the problem of earthquake prediction, is still poorly understood. This implies that in cases of earthquake disasters, mitigation is more important than prediction.

Premature evacuation of inhabitants may create more disorder than an unexpected earthquake, because of disruption of the economy, blocking of highways and obstruction of service facilities such as fire brigades, water works, medical care and communication means for survivors of the earthquake.

In earthquake prone regions, guidance, instruction, education and continuing emergency preparedness are of utmost importance. People should learn how to react in the case of sudden earthquake. Authorities should avoid making specific prediction available to the general public to prevent panic and provide it only to related agencies which should be optimally prepared for emergencies. Construction of seismic zoning map for risk areas, taking into acount rockfall, slope instabilities and liquefaction potentials, is a must.

Seismic building codes or rules for building construction should be rigorously applied. All construction should adhere to an accepted building code and special attention should be given to the vulnerability of essencial facilities which must remain functional during and after an earthquake. For this reason a close and intense cooperation is needed between environmental planners, architects, civil engineers, geotechnicians, geologists and seismologists.

The earthquake - resistance building research is undertaken by the Public Works Department. Pilot projects for public housing have been initiated in some of the earthquake-prone areas. Strong motion seismographs (accelerographs) are required to be installed in high-rise buildings in order to study the dominant seismic period of the area.

Investments in power and financing are necessary to bring about these preventive measures. Such an investment, especially in developing countries, is more effective than that for an elaborate program to succesfully predict an earthquake without taking into account the measures for mitigation as described above.

# VIII. EPILOGUE

## 1. SHORT-TERM PLANNING

Short-term plans are the following :

**a.** Preparation of regional seismotectonic maps which provide historical seismicity and tectonics. The maps can be taken as a basis for directing attention to potentially and seismically dangerous areas. Available maps have been provided by the Geological Research and Development Centre to the Ministry of Public Works and Ministry of Social Welfare.

**b.** Collection of historical seismic data, earthquake intensity, magnitude and ground motions that occurred in the past combined with geological informations on rock types, structures, especially active faulting, delineation of seismic hazard zonations is in progress.

**c**. Bilateral and multilateral cooperation with other leading institutions is very helpful. Some plans have been made for increasing capability in seismic hazards assessment, practice of seismic hazard and risk asssessment, and technical presentation of theory and application of probabilistic hazards and risk mapping.

## 2. LONG-TERM PLANNING

Long-term plan is to implement interdisciplinary approach of geology, geophysics, seismology and historical data on seismicity to establish Probabilistic Ground Motion Map of Indonesia .

The expected outcomes from the above are:

**a**. To enhance the geoscientific capability of Indonesia in conducting comprehensive research in earthquake monitoring;

**b**. To develop more precise knowledge on the characteristics of active fault movements in the region;

**c**. To mitigate the effects of an earthquake event in an earthquake prone region.

It is hoped that the improved knowledge of the geodynamics of Indonesia and better understanding of the geologic hazards, especially earhquakes, will contribute to the mitigation of the effects of such occurrences in various areas.

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