Chapter 2

CONTEXT AND EARTHQUAKE OF 16 JULY 1990

2.1 Area Affected by Earthquake

The July 16, 1990 earthquake was felt throughout most of Luzon island, but the majority of the resulting death and destruction occurred in the northern area--Regions I, II, III, and the Cordillera Administrative Region (CAR). The provinces of Nueva Ecija, Nueva Vizcaya, Tarlac, Pangasinan, La Union, and Benguet, especially the cities of Baguio and Dagupan, were the most seriously affected. (See Figure 2.1-1)

The earthquake-affected regions, Region I, II, III, and CAR, comprise about one-fourth the total land area of the Philippine archipelago or about half of the land area of Luzon.

Table 2.1-1
Land Area of the Earthquake-Affected Regions

	Land Area	(%)
Philippines	300,000 sq. km.	(100.00)
Luzon	141,395	(47.10)
Region I	12,840	(4.28)
Region II	26,837	(8.95)
Region III	18,230	(6.08)
CAR	18,293	(6.10)

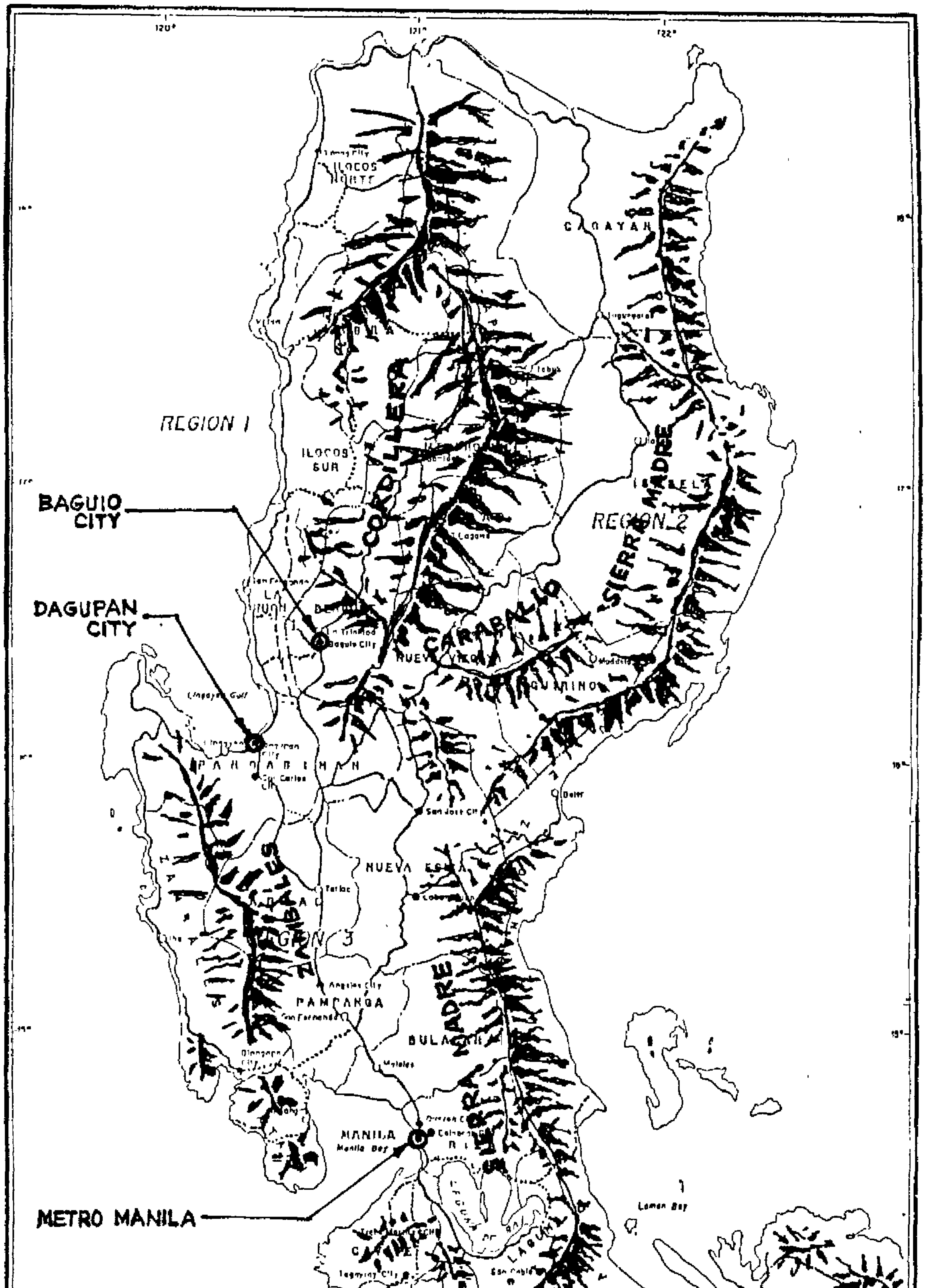
Source : NEDA, The Luzon Area Development Framework and Strategic Investment Program, 1990

2.1.1 Region I

Region I or the Ilocos Region is composed of four provinces on the northwestern coast of Luzon: Ilocos Norte, Ilocos Sur, La Union, and Pangasinan. The topography of this region is generally level, especially along the coastal strip area and most of Pangasinan, but becomes even mountainous along its eastern and southwestern boundaries. This is where the region begins to merge with the Cordillera and Zambales mountain ranges, respectively.

The population centres of the region dot the coastal area with the cities and major municipalities of Laoag, Vigan, Dagupan, San Fernando, and Lingayen serving as urban nodes.

Figure 2.1-1
Northern Luzon



Two prominent river systems of Luzon flow into China Sea through Region I. One is Agno River, which rises in the northern Benguet mountains of the adjacent Cordillera Region and then flows south into Central Luzon, where it divides into several channels before emptying into the gulf of Lingayen (in the Dagupan area). The other is the Abra River, which flows from the Cordilleras to the Ilocos Coast.

2.1.2 Region II

Region II, the Cagayan Valley, occupies the northwestern portion of Luzon. It is flanked by three mountain ranges: the Cordillera in the west, the Sierra Madre in the east, and the Caraballo in its southern boundaries. The Sierra Madre range shields the valley from the seasonal typhoons which originate southeast of the archipelago. The Caraballo mountain range separates Region II from Region III, the Central Luzon Valley, with direct land access between the two regions being confined to the Dalton Pass route.

The largest river system of Luzon, the Cagayan River, runs the entire length of the valley. The river originates in the Caraballo mountains and flows north to the sea at Aparri. The region's major population centers--Aparri, Tuguga-rao (the regional center), Ilagan, and Cauayan--are located near the river. Region II contains the provinces of Batanes (a small island group north of Luzon) and the four Luzon provinces of Cagayan, Isabela, Nueva Vizcaya, and Quirino.

2.1.3 Cordillera Administrative Region (CAR)

The CAR is defined mostly by the Cordillera mountain range in the central part of northern Luzon. The region separates Regions I and II.

The mountainous CAR contains eleven major basins with a total of twenty-two rivers. Eighty percent of the region is covered with forests. The region is endowed with economically important gold and copper deposits.

The CAR is composed of the provinces of Abra, Benguet, Ifugao, Kalinga-Apayao, Mountain Province, and the city of Baguio. Baguio City, which is located near the southern edge of the Cordilleras, is the region's largest urban centre.

2.1.4 Region III

Region III or the Central Luzon Region occupies the central plain of Luzon and is the closest, among the earthquake-affected regions, to Metro-Manila (National Capital Region or NCR). The region contains the second most extensive river system of Luzon, the Pampanga River, which originates in northern Nueva Ecija and flows south into Manila Bay. Although the region has the smallest land area among the affected regions, it has the largest population, about 6.23 million. Region III has six provinces: Bataan, Bulacan, Nueva Ecija, Pampanga, Tarlac, and Zambales. Its largest population centres are Malolos, San Fernando, Angeles, Olongapo, Cabanatuan, and Tarlac, all connected by the Manila North Road.

2.1.5 Regional Population

The earthquake-affected regions have a total population of about 13.7 million, which represents a little less than a quarter of the total population of the Philippines.

Table 2.1.5-1
Population of the Earthquake-Affected Regions

	1990 Population	Percent
Philippines	60.5 million	(100.0)
Luzon	34.3	(56.7)
Region I	3.75	(6.2)
Region II	2.48	(4.1)
Region III	6.23	(10.3)
CAR	1.27	(2.1)
NCR	8.11	(13.4)

Source: NEDA, The Luzon Area Development Framework and Strategic Investment Program, 1990.

2.1.6 Regional Economy

Luzon had a combined Gross Regional Domestic Product for 1989 of P67 billion at constant 1972 prices. This is 62.5 percent of the country's gross domestic output. The NCR accounts for almost 50 percent of the total Luzon output; the earthquake-affected regions account for about 23 percent of Luzon's output or about 15 percent of the total national output.

Table 2.1.6-1
Gross Regional Domestic Output of the Earthquake-Affected Regions, 1989

	GRDP (P million)
Philippines	107,146
Luzon	67,026
Region I	3,388
Region II	2,104
Region III	8,792
CAR	1,665
NCR	33,256
Other Regions	40,120

Source: NEDA, The Luzon Area Development Framework and Strategic Investment Program, 1990.

The economy of the earthquake-affected regions, like most of Luzon and the rest of the country, is agriculture-based. Rice, the staple crop, is grown in all of the regions.

Sugar, corn, vegetables, coconuts and other fruits are also major crops, and tobacco and cotton are cultivated in selected areas. As a whole, the earthquake affected regions account for about 30 percent of the total value added in agriculture. The fishery sector is also an important part of the economy throughout most of Luzon, especially in the coastal areas. Mining, especially of gold, copper, silver, and chromite, is a significant foreign exchange earning activity in the Zambales and Cordillera mountain ranges. Industrial activities, including light manufacturing and food processing, are concentrated around the major urban centres, especially in and around the San Fernando-Angeles corridor in Pampanga, in the Bulacan towns close to the NCR, in San Fernando, La Union, Baguio City, Dagupan City, Laoag, Tarlac, San Carlos, Cabanatuan, Cauayan, and Tuguegarao. Cement manufacturing plants are also located in Pangasinan and La Union. Tourism is a major source of income in Baguio (the foremost tourist destination outside of Manila), Angeles City and Olongapo City (which cater to the Clark and Subic military bases respectively), and in the coastal areas of La Union, Zambales, and the Ilocos provinces.

2.1.7 Regional Transportation Network

The strong Manila orientation of the economy of the earthquake affected regions is reflected in the transportation network of Luzon. The two major roads which run through the northern part of the island, the Manila North Road and the Cagayan Valley Road, converge just north of Manila in Region III, funneling most of the northern regions' produce to the NCR through Manila's north expressway. This dendritic flow of goods has contributed to the emergence of Region III, the Central Luzon Region, as a major industrial and service node. It has also led to, however, the lack of significant lateral linkages in northern Luzon, a pattern reflecting the structure of the Cordillera mountain range. This was evident after the July 16 earthquake when the Cagayan Valley road became impassable in the Dalton Pass area and when land access between Region II and Manila was possible only through the extremely circuituous Allacapan-Laoag route. (See Figure 2.1.7-1)

2.2 Earthquakes and Other Geological Hazards in the Philippines

The Philippine Archipelago is exposed to natural disasters of large scale and relatively high frequency of occurrence. Besides typhoons, other violent natural hazards such as earthquakes, volcanic eruptions, landslides, tsunamis and floods, are causing enormous property losses exceeding the economic capacity of the affected region and the entire country. During the foreseeable future with the rapid growth of industrial development in the hazard prone regions accompanied by urban expansion and increased population, it should be expected that natural disasters will become increasingly destructive leading to economic and social instability with higher intensity as it has been experienced in the past history of the country.

The geologic and tectonic setting of the Philippines renders it particularly vulnerable to two major geologic hazards: volcanic eruptions and earthquakes. The Philippines has about 220 volcanoes which are distributed within five trench-related volcanic belts (Fig. 2.2). There are 21 active volcanoes which had erupted during historic times and are therefore regarded as active. Five of the twenty-one active volcanoes have a relatively shorter response period (8 to 50 years between eruptions) and are the most active ones in the Philippines. Volcanic eruptions generate the following adverse environmental impacts: loss of agricultural lands; reduction in agricultural productivity; destruction of infrastructure; and in particular populated areas, producing economic losses and social disorder.

Earthquakes in the Philippines account for over 3.2% of the world's seismic activity or 26.5% of energy released based on all earthquakes with $M \geq 7.9$ in the interval 1904 - 64. The frequency distribution map showed clustering of earthquakes within zones bounded by trenches, a belt of earthquakes coincided with the Philippine Fault. Based on the frequency distribution, seven major seismogenic zones generating earthquakes (Fig. 2.3), are recognized and documented (1,2 and 3). Presented map of maximum observed earthquakes (Fig. 2.6) and distribution of average return period of occurrence of earthquakes with intensity VII (MM scale, Fig.2.7) are prepared based on the historical earthquakes (pre-1900) and instrumental data for the period 1589-1983. Epicenters of the events with $M \geq 6.5$ or MM intensity $I \geq VIII$ are given in table 2.2.1 (from Lomnitz, c., 1974). From these two maps it is quite evident that the largest urban areas in the country including Manila could be exposed, with high probability and frequency of occurrence, to the catastrophic earthquakes (MM intensity IX - XI). Considering that the most recent earthquake of 16 July 1990 is filling a predicted seismic gap in Central

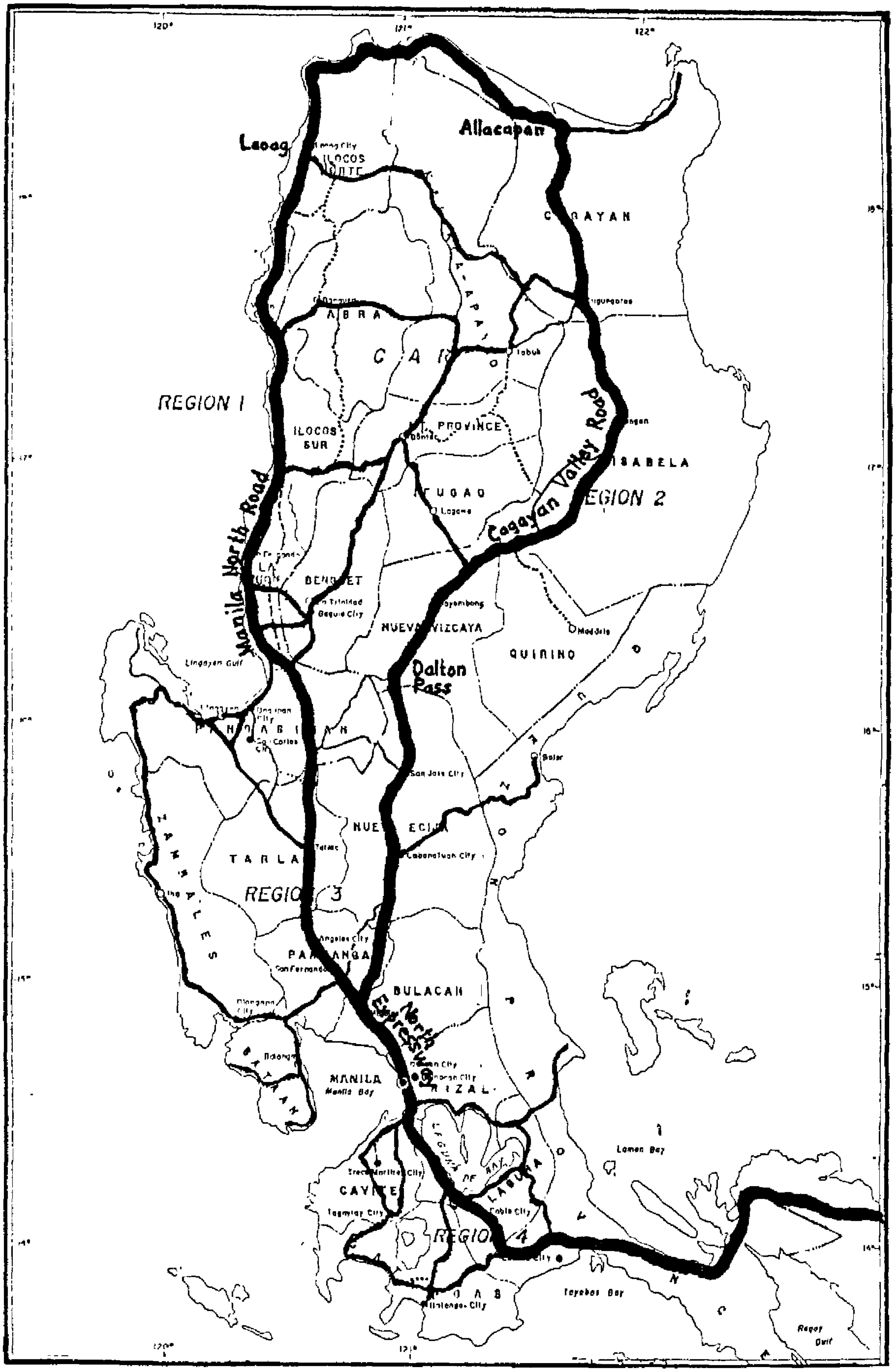
Luzon, observed maximum intensities in this area should be substantially increased (e.g. Baguio).

The archipelagic nature of Philippines makes its coastal areas exposed to adverse impact of storm surges, tsunami and sea level changes. Storm surges may cause destructions to the areas below 2 meters above sea level, but tsunamis can affect coastal areas well above 4 - 5 meters elevation (Fig. 2.8). Particularly exposed to tsunami hits are the coastal areas of Southern Mindanao facing the Celebes Sea, devastated by tsunami generated by 1976 Moro Gulf earthquake (3.4).

Flooding of low-lying areas and occurrence of landslides in the highland slope areas are also frequent destructive phenomena to the rural and urban areas, transportation systems and lifelines. Floods and landslides are induced by the big rains associated with the southwest monsoon, but large scale landslides, rockfalls and mudflows could be triggered by earthquakes or failure of major dams can cause floods and landslides of large scale.

Figure 2.1.7-1

**ROAD NETWORK:
EARTHQUAKE IMPACTED REGION**



Although it is quite evident that the Philippine Archipelago is frequently exposed to disastrous geologic hazards and typhoons, considering that notable successes in disaster mitigation have occurred in the world in recent years, largely as a result of scientific and technological progress in understanding the causes and means for reducing the effects of natural disasters, application of this knowledge and available technologies in the Philippines can save thousands of lives and greatly lessen human suffering and property losses in the near future. The United Nations International Decade for Natural Disaster Reduction (IDNDR) designating 1990's for this important step forward in creation of international cooperation and technical assistance, in particular to developing countries, is a most suitable framework to create multi-hazard approach for natural disaster management in the Republic of the Philippines, with assistance of UNCHS in transfer of developed technologies and their implementation in reduction of the consequences of the 16 July 1990 Luzon earthquake.

2.3 Seismic Characteristics of Luzon Earthquake of 16 July 1990

On July 16, 1990 (at about 16:26 Hrs. local time), an earthquake of magnitude 7.8 on the Richter Scale occurred. The earthquake epicenter was initially located at 13 km. NNE of Cabanatuan City. It was later pointed out that there were two earthquakes, the other occurring about 20 km east of Baguio. The earthquake affected an area of about 100,000 sq. km. in the island of Luzon causing 1,648 deaths, leaving about 27,000 homeless families, seriously affecting over 280,000 families, and producing enormous damage to buildings, transportation systems, lifelines, ports and other infrastructure facilities, estimated as total direct loss of about 500 million US dollars.

Based on USGS-PHILVOCS and Hiroshima University-PHILVOCS Field investigations, the following could be summarized in respect to surface faulting and post-earthquake seismic investigations.

2.3.1 Surface faulting:

The fault segments which were responsible for the July 16 earthquake are parts of the Philippine Fault zone running along the Gabaldon area (near Dingalan) through Rizal town and San Jose area and follows the Digdig-Talavera River from the San Jose area through Digdig, Nueva Ecija to NW of Capintalan, Nueva Ecija. Most parts of these segments were previously mapped as active faults and its recent activity was further corroborated by the July 16 event. The crustal motion is classed as left-lateral slip, that is, part of Luzon northeast of the faults shifted horizontally northwestward relative to the rest of Luzon. The set of faults in Luzon is comparable to the right - lateral San Andreas fault system in California; each is a very long principal fault within its respective region of the Circum-Pacific belt.

At most of the places observed, the horizontal crustal shift exceeded 3 meters, with the largest displacement so far recorded measuring about 6.2. meters near the northern terminus of the reconnaissance area. Even greater displacements may have occurred in the as-yet-unsearched mountain regions farther northwest. These horizontal displacements in Luzon are among the largest of their kind to occur anywhere in the world during this century. (Fig. 2.9).

Vertical displacements along the Philippine and Digdig Faults were relatively small and variable: the northeast side was uplifted relative to the southwest along some sections of the fault but the opposite was the case elsewhere. Vertical displacements in irrigated rice fields have submerged some paddies and lifted others above the present irrigation channels.

No significant displacement occurred during the observation period (between the 13th and the 21st post-earthquake day), so the team judged that little or no further slip will occur along this section of the fault. However, displacements along unmonitored fault breaks, e.g., along the Digdig Fault zone where offsets are large and aftershocks appear to be continuing, may still be increasing.

2.3.2 Seismic Investigation:

The main shock was recorded on the PHIVOLCS network of permanent seismic stations throughout the country. Shortly after the main shock, the Institute deployed three portable seismographs in order to locate aftershocks. The USGS-PHIVOLCS team deployed four GEOS (Generalized Earthquake Observation System) digital seismographs, first in the epicentral area of the main shock and later in both the epicentral and Baguio areas. The GEOS seismographs can record seismic signals over a broad spectral and dynamic range. The magnetic tapes of digital data will be analyzed in Menlo Park, California for the spatial distribution of aftershocks throughout the two weeks of recording, and for various spectral and amplitude features of the signals.

The first array (Pantabangan, Marcos Village and Lupao, Nueva Ecija and Segobia Nursery, Bamban, Tarlac) was designed to locate aftershocks precisely, aided by precise temporal synchronization of stations to within 10 milliseconds throughout the deployment. The located aftershocks will help to constrain the depth(s) of main shocks and their rupture areas. The data can also improve the seismic velocity model for central Luzon, which will in turn improve PHILVOLCS location algorithms for future earthquakes.

The second deployment (Baguio; San Juan, San Fernando, La Union; Pantabangan dam, and Marcos Village) sought to further refine aftershock locations and to estimate attenuation of seismic waves between the aftershock source regions and these recording sites. Comparisons between Baguio and the other stations will also help to evaluate the degree to which the mountainous topography of Baguio might focus seismic energy near ridge crests.

The third deployment (paired stations at several sites in Baguio; Pantabangan Dam, and Marcos Village/Central Luzon State University (CLSU) was designed to quantify the effects of local site geology and topography on ground shaking and seismic wave attenuation, as well as to locate additional aftershocks. Comparison of single aftershocks on these paired stations will determine whether unusual amplification or other modification of the seismic waves occurs at any of the sites. Comparison of strong motion records from soft alluvial sediments at CLSU and hard rock at Pantabangan Dam and Baguio should indicate the extent to which high frequencies of the seismic waves might be attenuated in the lowland alluvium and amplified in mountainous areas.

Earthquake-induced landslides, rockfalls and liquefaction added significantly to the damage and continuing problems of the July 16 Luzon earthquake. Roads, bridges, buildings, and irrigation systems were affected directly by ground failure; in addition, search and rescue efforts were delayed by landslides, as will be the recovery and reconstruction, especially during the rainy season.

The effect of earthquake in land instabilities (ground failures) due to their wide spreading and very specific effect in different areas will be discussed separately in Chapter 3 in the context of earthquake effects in Baguio and Dagupan City as well as major effects due to land instabilities on transportation facilities (Chapter 4), and other facilities and areas.

2.3.3 <u>Strong Motion Records</u>:

Besides very carefully planned and performed surface faulting field studies and seismic investigations, no strong motion instruments have been installed to serve temporary and permanent needs which will be discussed in Chapter 7. Existing 14 to 20 strong motion instruments installed in the country before the earthquake of 16 July 1990 were not operational. It will be of utmost importance to bring them into operational conditions as soon as possible and to install material strong motion instruments network with urgent realization in the affected region and urban areas.

An attempt is made hereafter to make an assessment of the range of amplitude and frequency content of damaging earthquake ground motions based on the JSCE team (12) field measurements, and preliminary analysis performed by Midorikawa, S. (13) as well as prevailing failure and damage patterns of buildings. Distribution of peak ground accelerations as calculated (13) are presented in Fig. 2.12. The range of estimated values presented in the map could be confirmed with analysis of overturned subjects in Baguio City (0.3 - 0.4 g; JSCE team), estimated value of 0.18 g at City of Dagupan is confirmed by analysis of liquefaction potential for the obtained SPT test and SCT test parameters. However, relatively low nonstructural damage of rather weak buildings is not in proper agreement with estimated peak ground accelerations.

In respect to the frequency content, an impression could be established based on measured microtremors at the sites in Baguio and Dagupan City (Reference 4, Chapter 3) as well as damage patterns of the buildings. From the evidence of non-damaged elevated steel water tanks in both cities, and possible resonance conditions in the range of 0.2 to 0.4 sec. for the prevailing soil conditions and measured periods of vibration of the buildings, it can be estimated that ground motions have been amplified significantly in the range of 0.2 to 0.5 sec, thus representing dominant short period induced earthquake ground motions even on a larger distances from the causative fault.

Dominant vibrational effects producing failure and large scale damage on buildings and structures as well as prevailing land instabilities in the affected region by the earthquake of 16 July 1990 are presented with geological sketch in Fig. 2.13.

Table 2.2-1

EPICENTRAL PARAMETERS AND MAGNITUDES OF DESTRUCTIVE EARTHQUAKES IN THE PHILIPPINES IN THE PERIOD 1589-1983

	Date	Time (LST)	Location Lat °N	Long °E	Magnitude		I_o
1.	1599 June 21	10:00 a.m.	14.60	121.00			VIII
2.	1619 Nov 30	noon	18.17	121.60			X
3.	1743 Jan 12	5-6:00 p.m.	14.00	121.60			X
4.	1787 July 13	6:45 a.m.	10.70	122.55			X
5.	1796 Nov 05	2:00 p.m.	16.05	120.30			X
6.	1852 Sept 16	6:30 p.m.	13.95	120.40			IX
7.	1863 June 03	7:20 p.m.	14.63	121.40			X
8.	1869 Aug 16	3:00 p.m.	12.17	123.69			IX
9.	1869 Oct 01	11:15 a.m.	14.82	120.82			IX
10.	1873 Nov 14	5:30 p.m.	13.11	122.98			VIII
11.	1880 July 18	12:40 p.m.	16.00	121.85			X
12.	1885 July 23	10:45 a.m.	8:43	123.60			X
13.	1889 May 26	2:23 a.m.	13.59	121.19			VIII
14.	1892 Mar 16	9:01 p.m.	16.06	120.42			IX
15.	1893 June 21	3:30 p.m.	6:88	125.83			X
16.	1897 Sept 21	1:15 p.m.	7.11	122.11	8.7	*	IX
17.	1897 Oct 19	7:52 p.m.	12.40	125.00	8.1	*	IX
18.	1902 Aug 21	7:17 p.m.	8.10	124.25			X
19.	1907 Nov 24	9:59 p.m.	13:30	123.40			X
20.	1911 July 12	12:09 p.m.	9.00	126.00	7.7	*	X
21	1913 Mar 14	4:47 p.m.	4.50	126.50	7.9	(PAS)	IX
22.	1917 Jan 31	12.02 p.m.	5.60	124.80			IX
23.	1918 Aug 15	8:20 p.m.	5.50	123.00	8.3	*	X
24.	1924 Apr 15	12:22 a.m.	6.50	126.50	8.3	*	IX
25.	1924 Aug 30	11:07 a.m.	8 1/2	126 1/2	7.3	(PAS)	IX
26.	1925 Nov 13	8:16 p.m.	13.00	125.00	7.3	(PAS)	VIII
27.	1929 June 13	5:26 p.m.	8 1/2	127.00	7.2	(PAS)	X
28.	1931 Mar 19	2:26 p.m.	18.30	120.20	6.9	(PAS)	VIII
29.	1937 Aug 20	7:59 p.m.	14.20	122.10	7.5	*	VIII
30.	1948 Jan 25	1:46 a.m.	10.90	122.10	8.3	*	IX
31.	1954 July 02	10:46 a.m.	13.00	124.00	6 3/4	(PAS)	IX
32.	1955 Apr 01	2:17 a.m.	8.00	124.00	7.5	(PAS)	X
33.	1968 Aug 02	4:19 a.m.	16.50	122.30	7.3	*	IX
34.	1970 Apr 07	1:34 p.m.	15.80	121.70	7.3	(NEIS)	IX
35.	1973 Mar 17	4:31 p.m.	13.41	122.87	7.0	(NEIS)	XI
36.	1976 Aug 17	12:11 a.m.	7.30	123.60	7.9	(NEIS)	X
37.	1977 Mar 19	5:43 a.m.	16.70	122.31	7.0	(NEIS)	VIII
38.	1981 Nov 22	11:06 p.m.	18.71	120.65	6.7	(NEIS)	VIII
39.	1982 Jan 11	2:11 p.m.	14.00	124.50	7.1	(NEIS)	VIII
40.	1983 Aug 17	8:18 p.m.	18.33	120.87	6.5	(NEIS)	VIII

* Lomnitz, C. (1974), Global Tectonics and Earthquake Risk, p. 231.

A. VOLCANIC ERUPTION HAZARDS

1. Lava Flows	Mayon Volcano, 1978
2. Pyroclastic Flows	Hibok-Hibok Volcano, 1951
3. Large-sized Tephra Falls	Canlaon Volcano, 1969
4. Ash Falls	Taal Volcano, 1976
5. Dome Growth	Mt. Vulcan, Camiguin, 1871
6. Hydrothermal Explosions	Tiwi, Albay, 1984
7. Large Magmatic Explosions	Sorsogon Caldera, 40,000 ybp

B. EARTHQUAKE HAZARDS

1. Ground Shaking	Manila, 1968
2. Fracture Movement, Fissuring	Ragay Gulf, 1974
3. Liquefaction-Differential Settling	Lemery, Batangas, 1911

C. HAZARDS FROM ROCK, SOIL AND SEDIMENT MOVEMENTS

1. Landslides & Rockfalls	Baguio City, 1986
2. Large Debris Avalanches	Mt. Iriga, 1641
3. Debris Flows & Mudflows	Mayon Volcano, 1986
4. Soil Creep, Expansion	Miag-ao, Iloilo, ongoing
5. Hastened Soil Erosion	Pantabangan, ongoing
6. Shoreline Erosion	Minglanilla, Cebu, ongoing
7. Ground Subsidence	Mankayan, Benguet, ongoing
8. Siltation	Bued River Basin, ongoing

D. HAZARDS FROM HYDROLOGIC ADJUSTMENTS

1. Rainwater Flooding	Manila, 1986
2. Riverwater Flooding	Tatalon, Q.C., 1976
3. Oceanwater Flooding	Manila , 2086
4. Dam or Levee Water Flooding	Maco, Davao, 1983
5. Local Tsunami	South Mindanao, 1976
6. Foreign Tsunami	Eastern Philippines, 1974
7. Seiches	Taal Lake, 1754
8. Groundwater Drawdown	Metro Manila, ongoing

E. HAZARDS FROM GEOCHEMICAL REACTIONS

1. Gas Emanations	active volcanoes, ongoing
2. Lake Sulfur Plumes	Lake Buhi, "seasonal"
3. Geochemical Pollution	Tongonan, Leyte, ongoing
4. Hydrocarbon Combustion	Moncayo, Davao, 1986

F. HAZARDS FROM GEOLOGIC ECCENTRICITIES

1. Lightnings of Volcanic Eruptions	Taal eruption, 1965
2. Meteorite Fall	Pasig, Pleistocene

Fig 2.1 General Presentation of Geologic Hazards in the Philippines (from Balce, G.R. and Ramos, R.G., 1987).

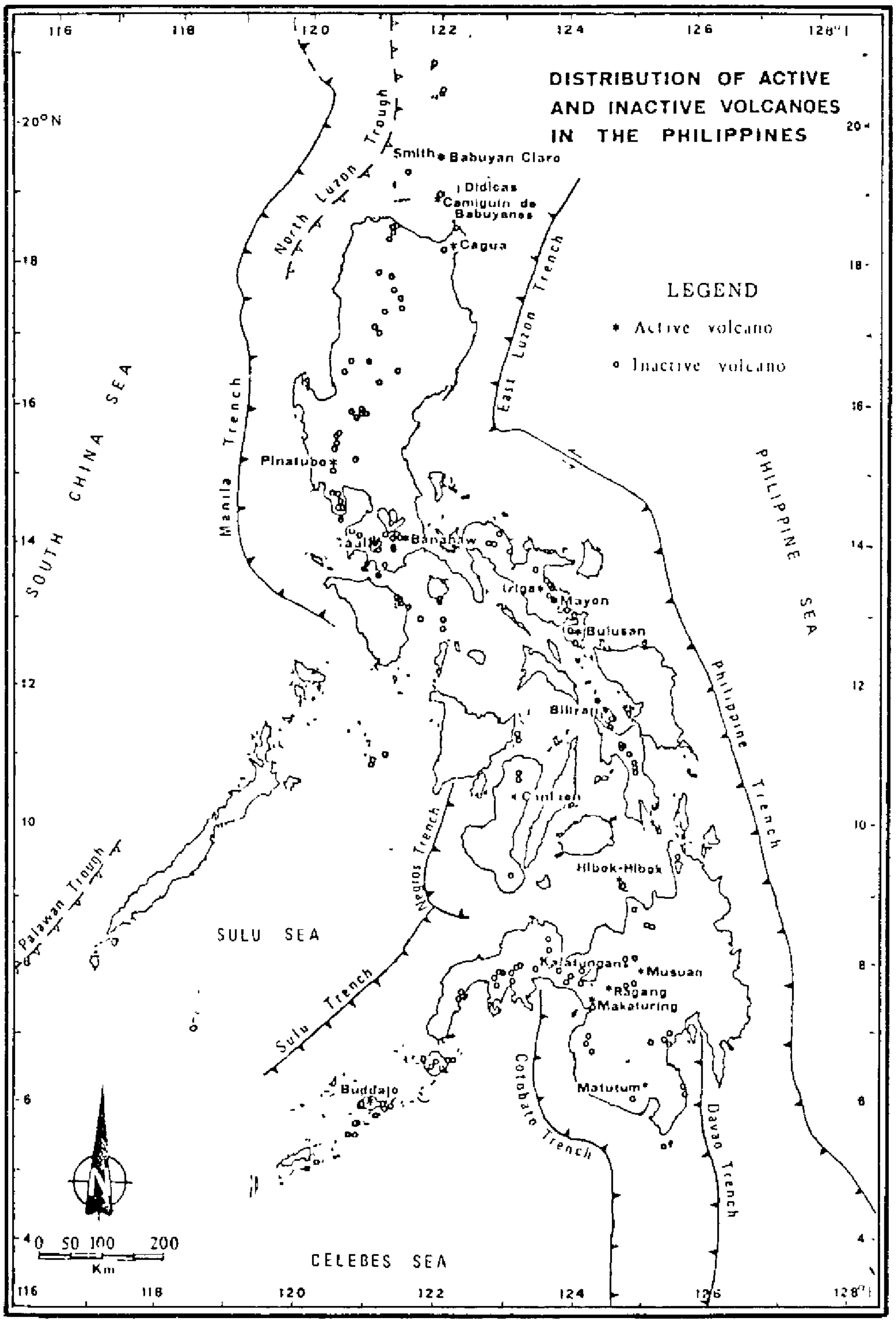


Fig. 2.2 Distribution of Active and Inactive Volcanoes in the Philippines (from Punongbayan, R.C., 1987).

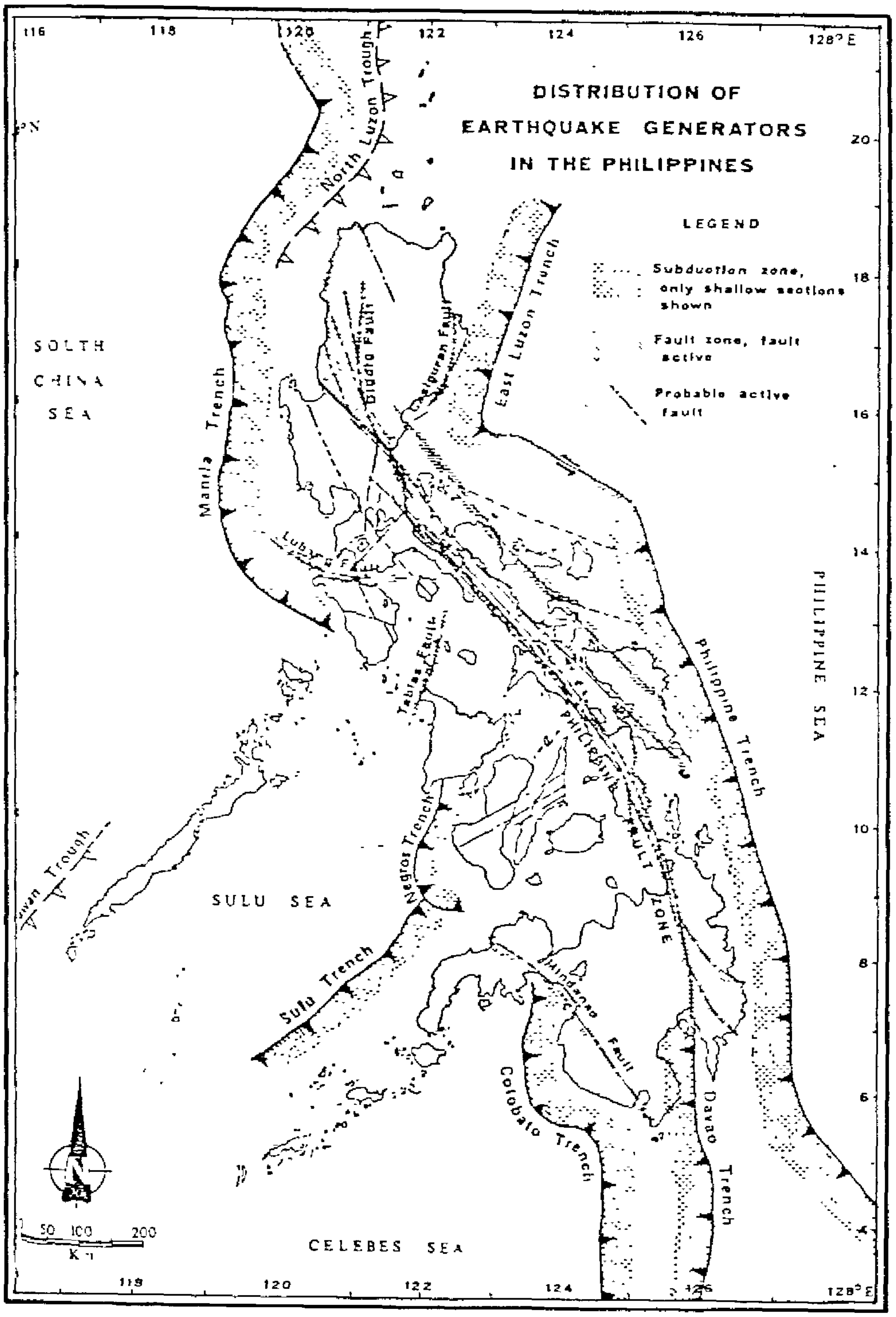


Fig. 2.3 Distribution of the Seismogene Zones, Generators of Earthquakes in the Philippines (from Punongbayan, R.C., 1987).

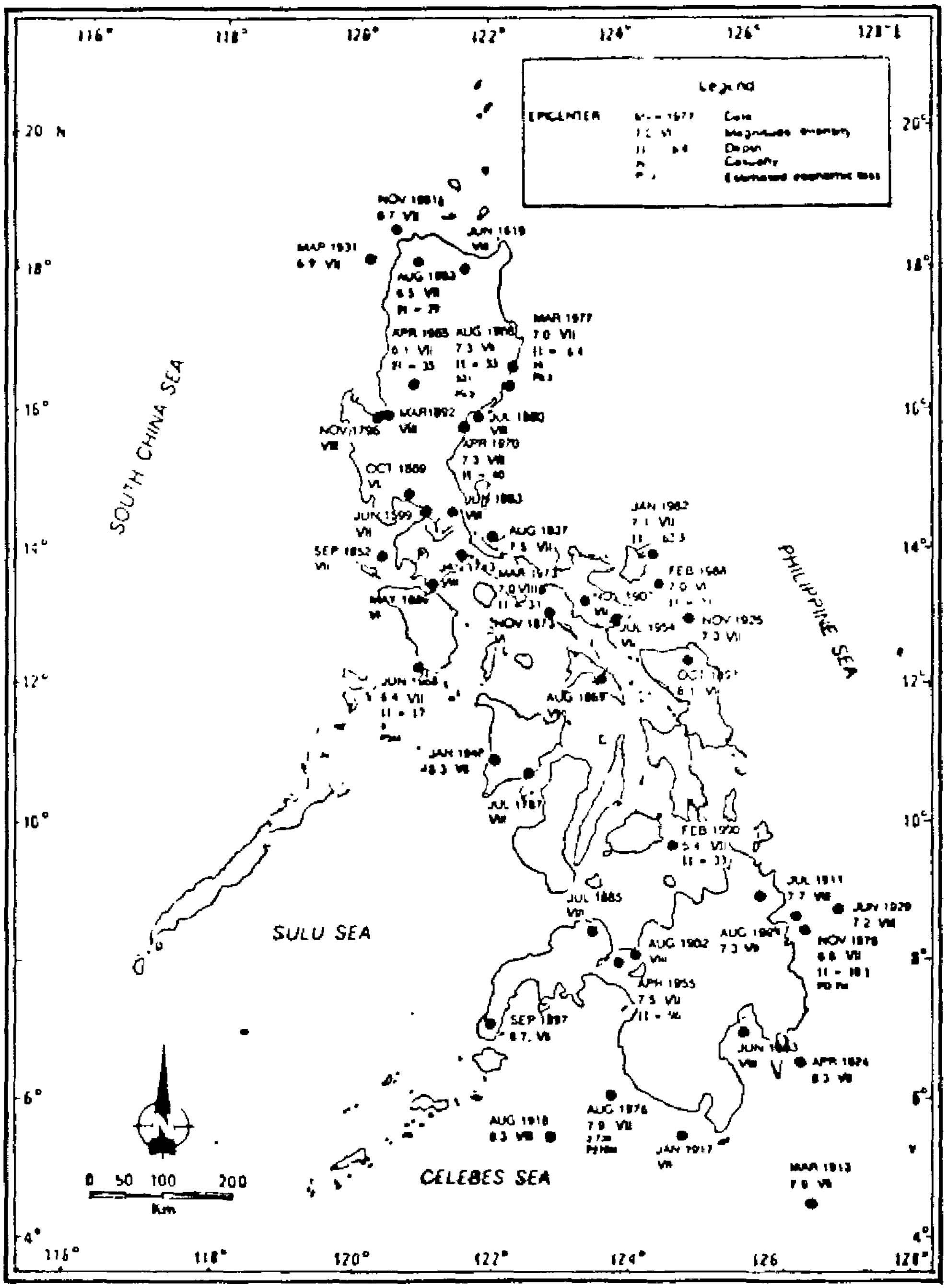


Fig. 2.4 Epicenters of Strong Earthquakes (M > 6, or Maximum Intensity > VI) in the Philippines for the period 1599-1988 (from PHILVOCS, 1990).

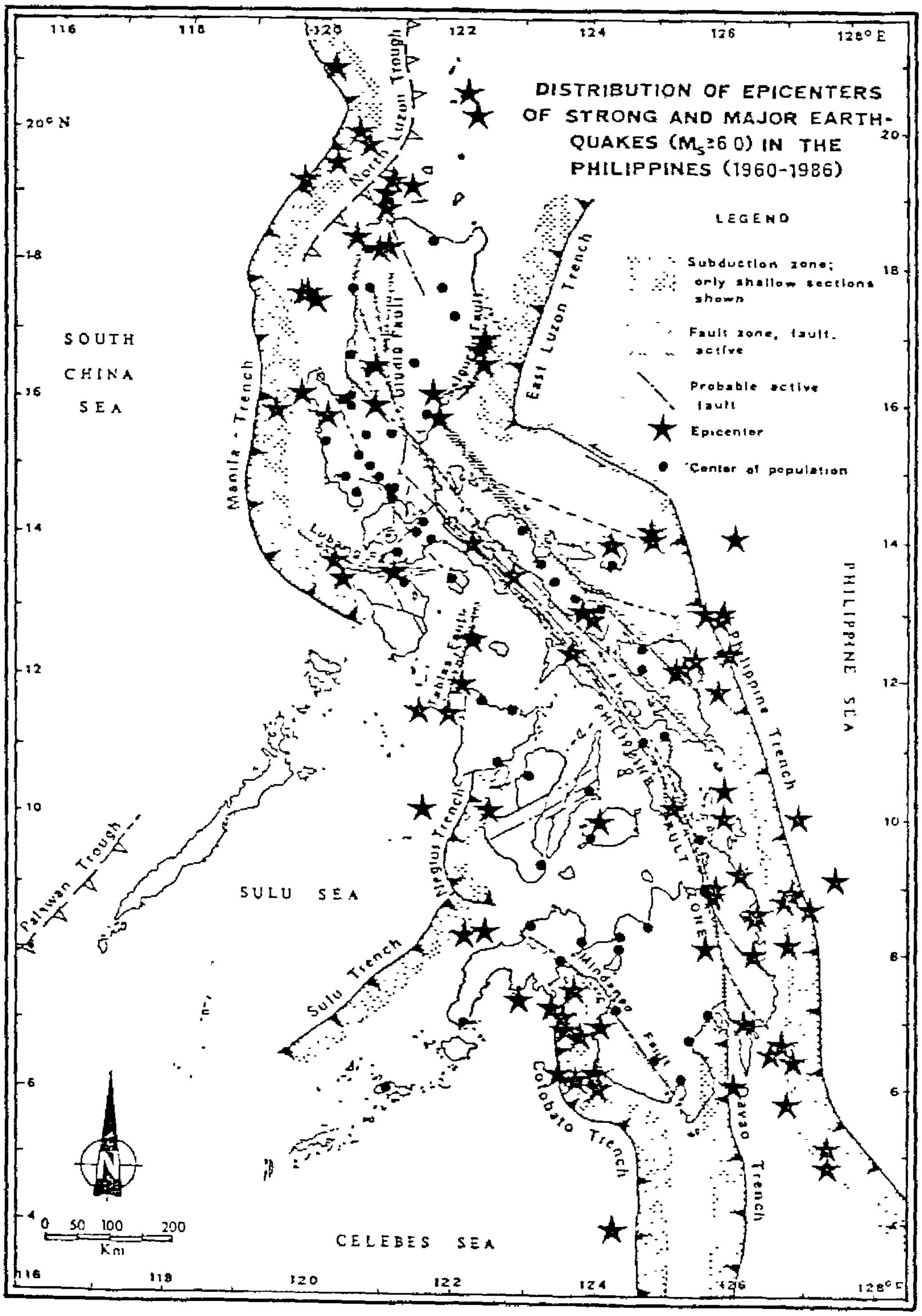


Fig. 2.5 Epicenters of Strong and Major Earthquakes (Ms $\geq$ 6) in the Philippines for the period 1960 - 1988, with major urban areas distribution (from Punongbayan, R.C., 1987).

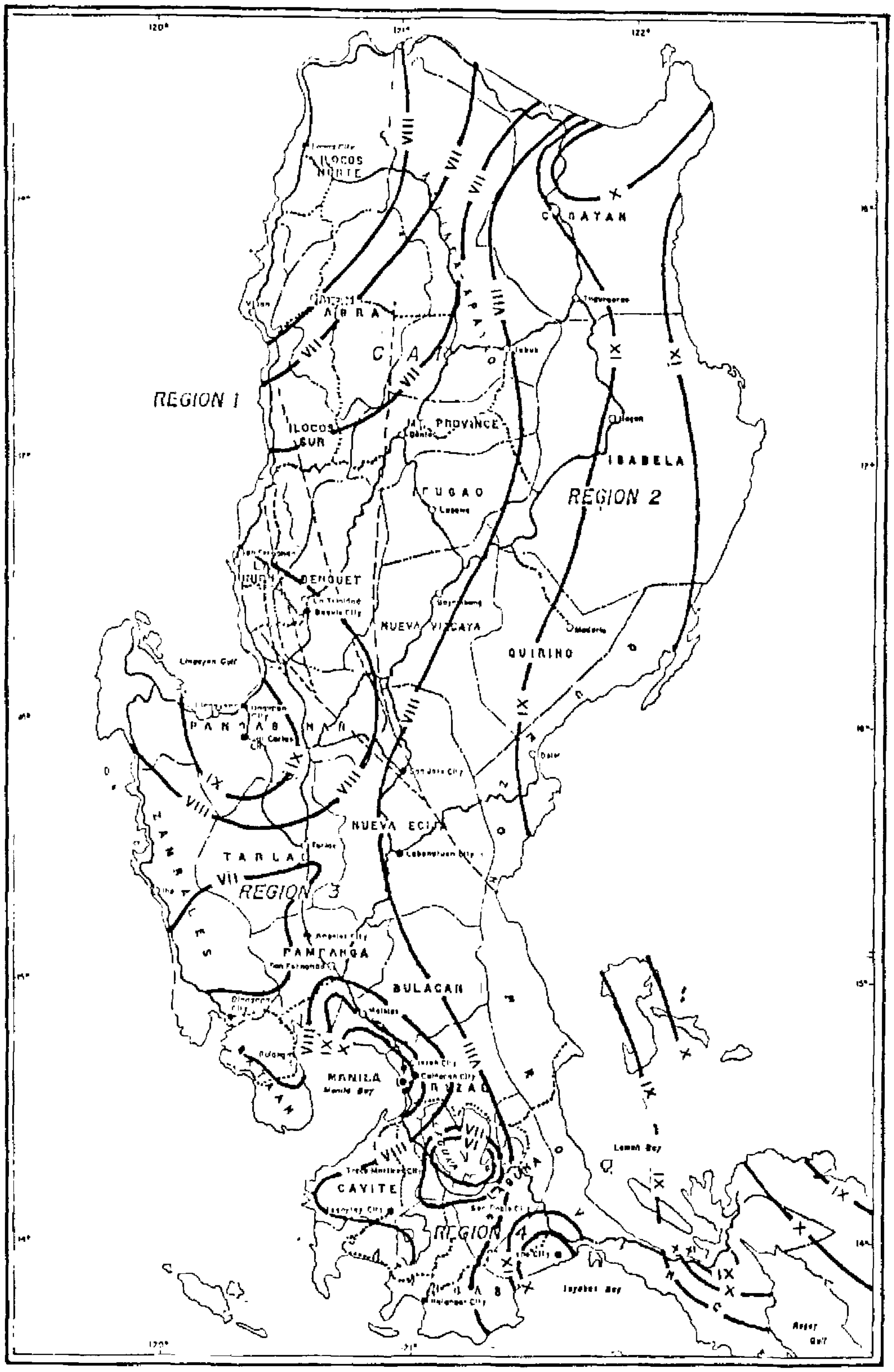


Fig. 2.6 Maximum Observed Earthquake Intensities Contours (MM Scale, from Garcia, L.C., et al, 1985).

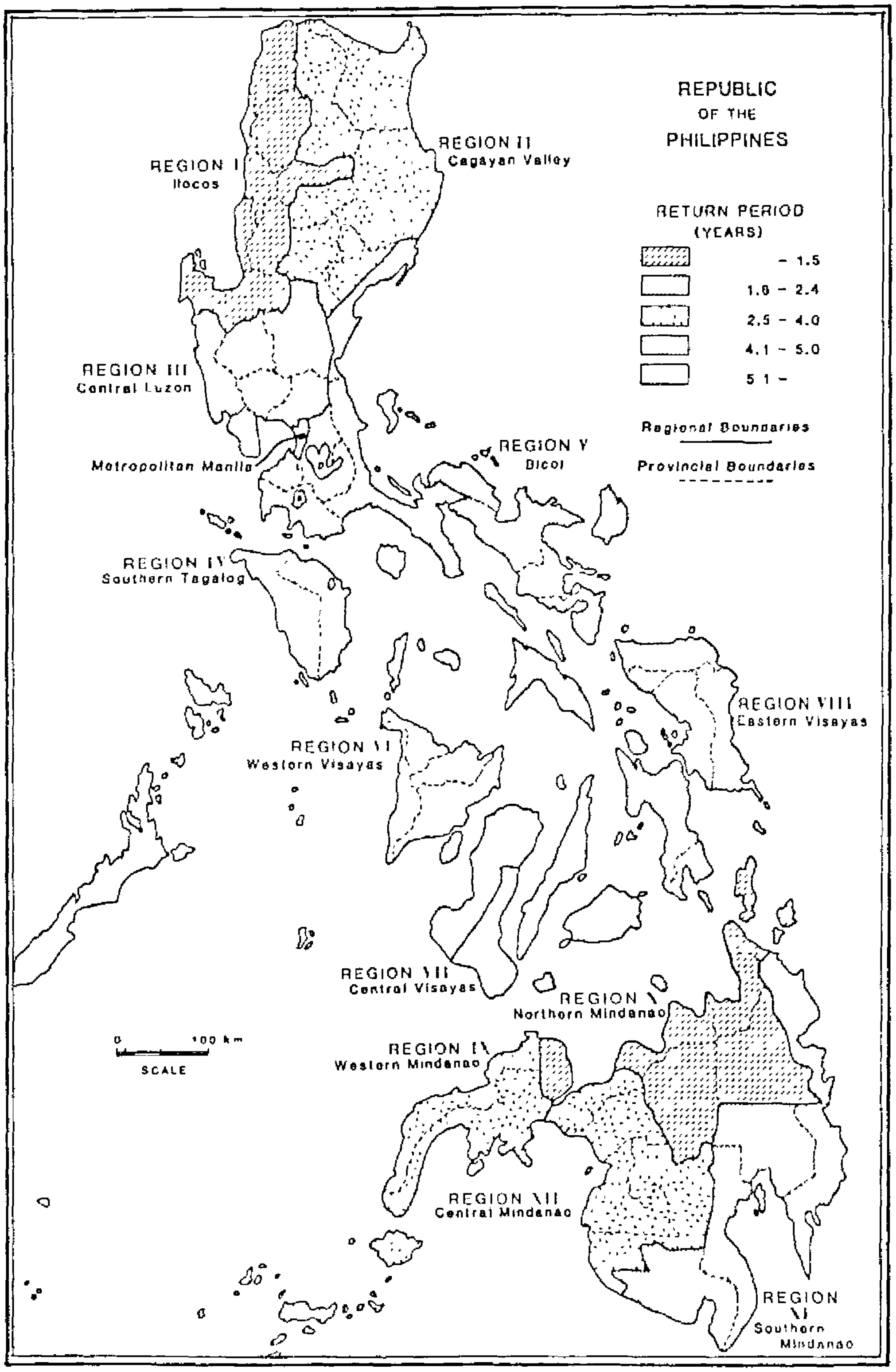


Fig. 2.7 Average Return Period for Occurrence of the Site Earthquake Intensity VII (MM Scale) (from Garcia, L.C., et al. 1985).

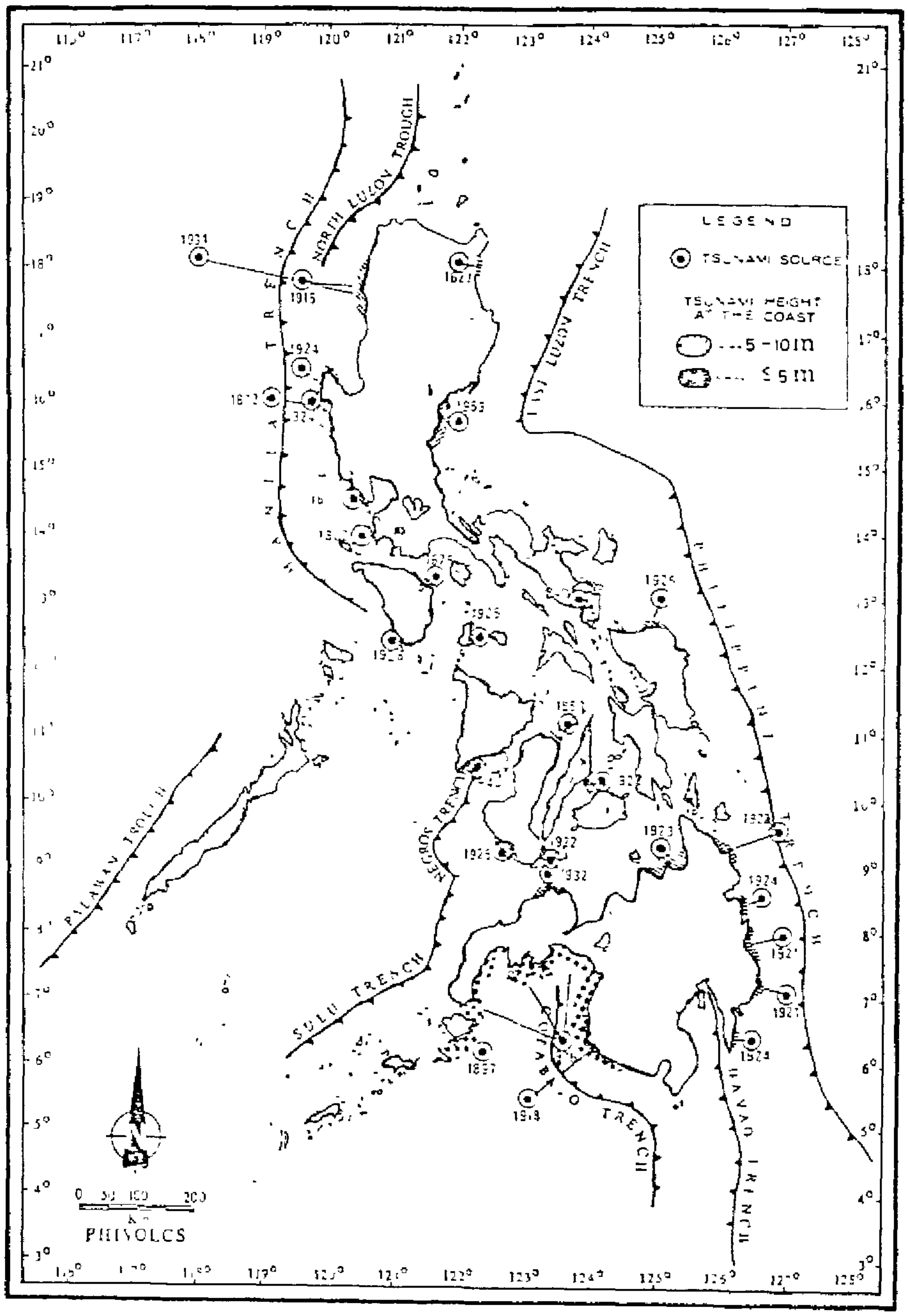


Fig. 2.8 Tsunami Prone Areas in the Philippines (from Uy, E.A. and Punsalan, B.T., 1987)

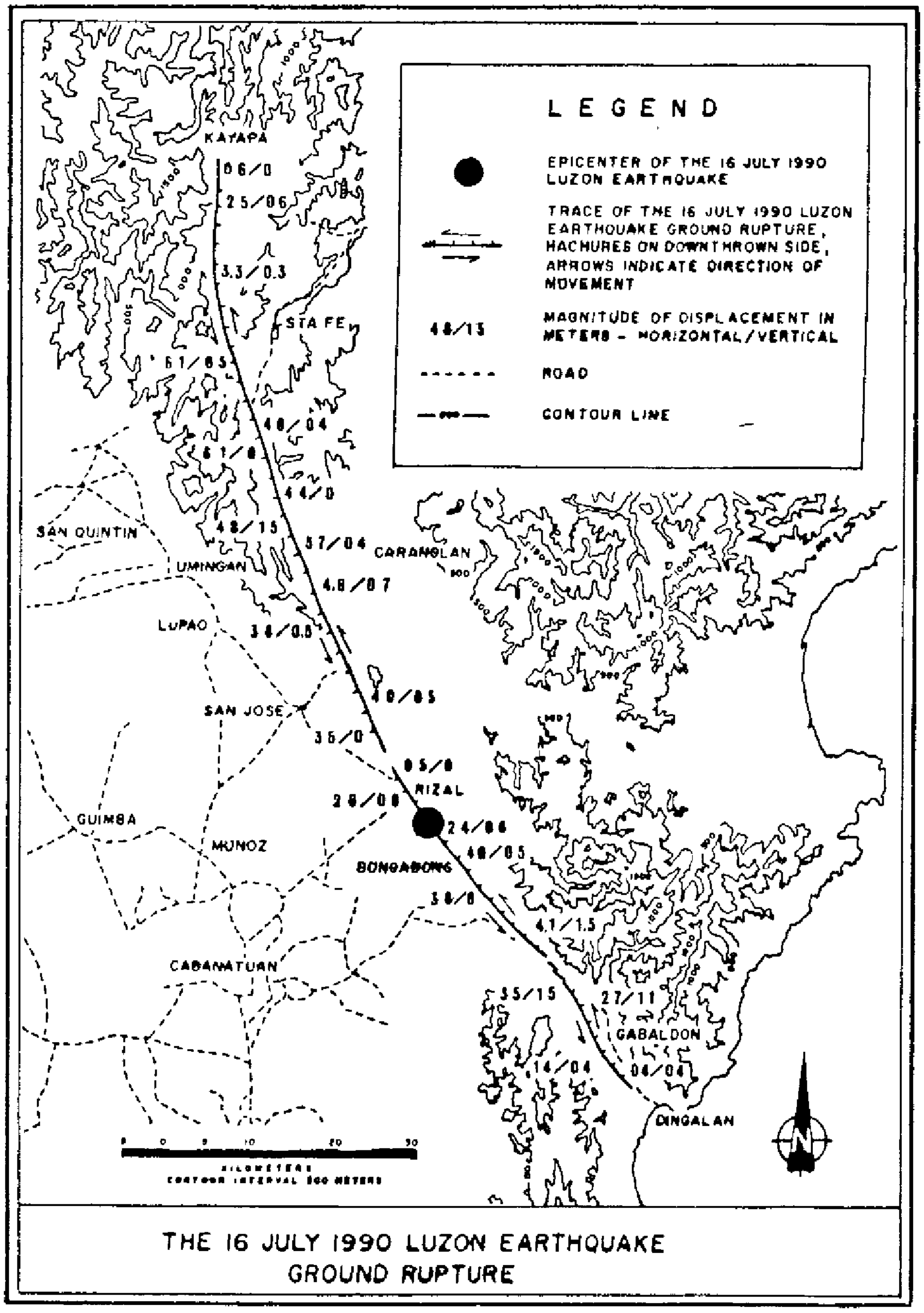


Fig. 2.9 The 16 July 1990 Luzon Earthquake main shock epicenter and inferred fault rupture with the magnitude of horizontal and vertical displacements (from PHILVOCS, 1990).

M.R.F.	I	II	III	IV	V	VI	VII	VIII	IX			
M M.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII

Fig. 2.10 Generalized isoseismal map (Rossi-Farel Scale) of the 16 July 1990 Luzon Earthquake (from PHILVOCS, 1990).

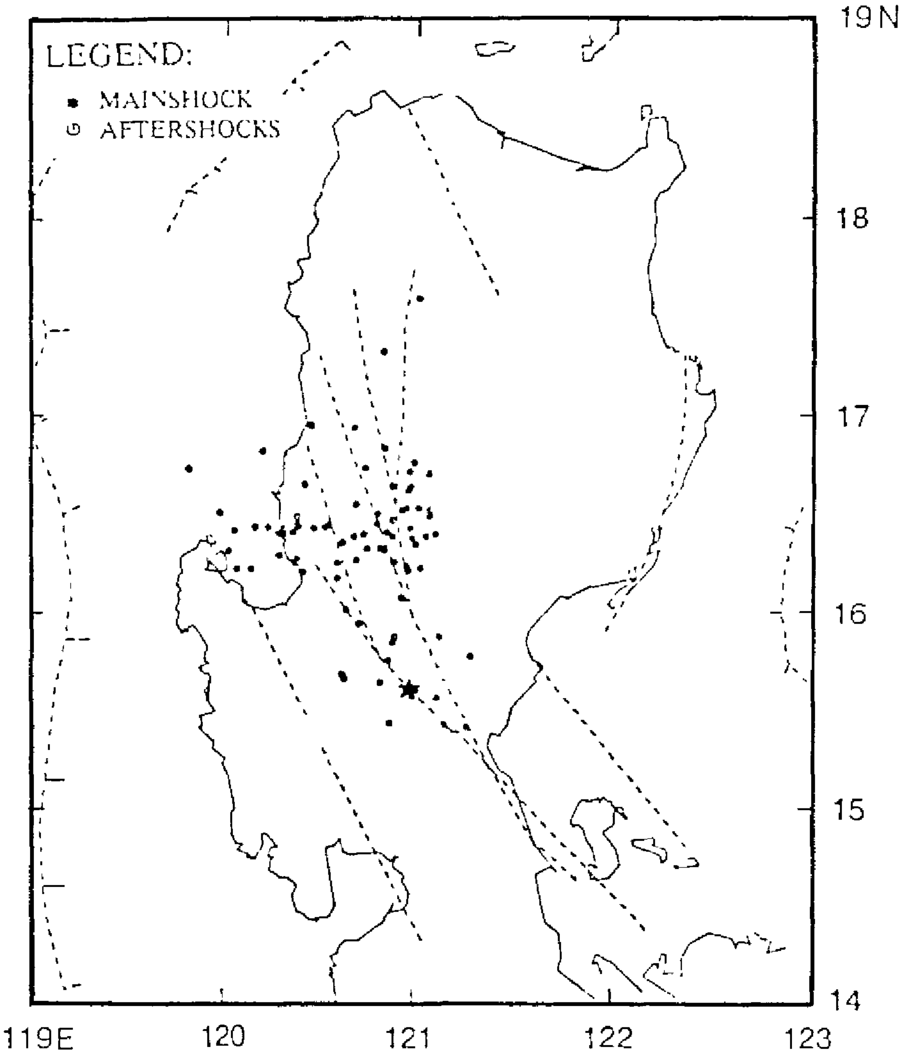


Fig. 2.11 Distribution of aftershocks of the 16 July 1990 Luzon Earthquake (after Sarmiento, J., Rasadas, A. and Macaranas, M.).

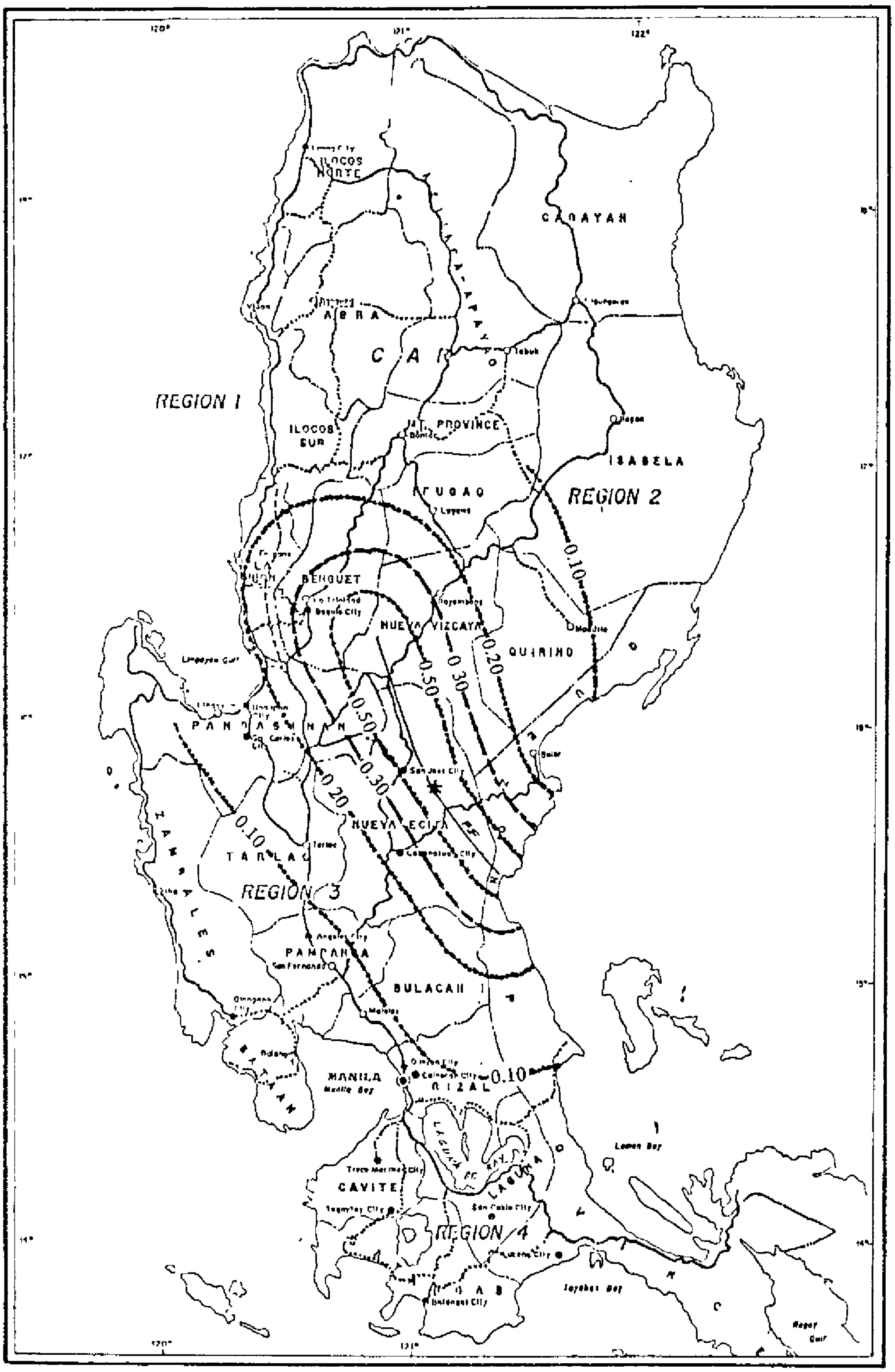


Fig. 2.12 Calculated distribution of peak ground acceleration in the affected area by 16 July 1990 Luzon Earthquake (from Midorikawa, S., 1990).

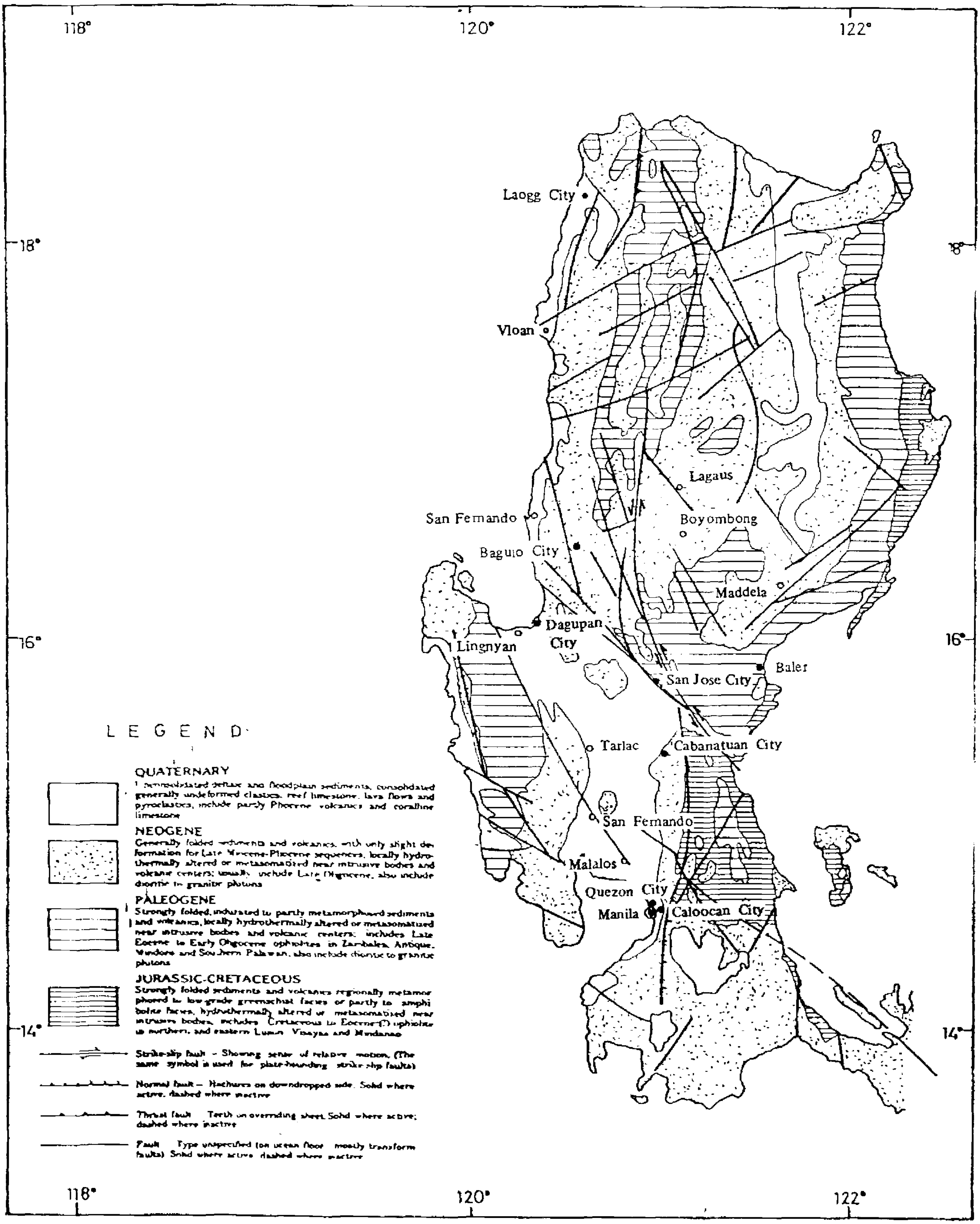


Fig. 2.13 Geological map of Luzon with principal tectonic features.

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