CHAPTER 7

PRE-EARTHQUAKE SEISMICITY AND THE 1990-91 AFTERSHOCK SWARM

7.1 The July 1990 earthquake and aftershocks

During the quake the region including the Sierra Madre Range and Cagayan Valley Basin was displaced northwestward, the part of Luzon south and west of the ruptured segment being subject to compression.

The accumulation of stresses mainly regarded the area southwest and west of the ground rupture, and north along its probable underground extension. As a result, a number of bridges, barriers and undulations along faults in the Central Valley basement and the Cordillera were progressively sheared off during the six months after the main quake. This caused numerous small and a few medium-intensity tremors throughout the central and north-western parts of the island, but with little damage.

The aftershock swarm was interpreted as a regional subsurface block rearrangement within the area of the July 1990 quake. The reorganization of the basement in Central Luzon, progressively affected the shallower crustal zone where confining pressure was lower, squeezing fractures and causing the intrusion of molten rock into chimney channels of volcanoes in the area.

The formation of foci, which mainly clustered southwest and west of the ground rupture zone, gradually shifted in a northerly direction, more or less following the same trend as the progressive ground rupture on July 1990. The depth of aftershock hypocenters progressively decreased a few days after the main quake.

On July 16, 1990, 32 shocks, most between 4.7 and 5.7 Magnitude, occurred worldwide within a period from 2 hours before to 16 hours after the Luzon earthquake (Table 7.1). Four were in Japan, two in Alaska, two in Taiwan, and one each in Iran, Guatemala and Chile, while the remaining 21, located in the Philippines, concentrated in the 14 hours after the Luzon quake. Twenty of these shocks affected Luzon and one Mindanao. This clearly shows the persistent high seismicity of Luzon associated with the strike-slip motion along the Philippine Fault.

7.2 Seismicity trends between 1985 and 1991 in the Philippines

The distribution of seismicity before 1990 was relevant to the July 16 earthquake and the associated aftershock swarm. Figure 7.1 shows the location of epicenters within the Archipelago during the period 1985-1991.

Seismic activity occurred during 1985 with clusters of epicenters in Baguio and Mindanao. The northwestern coast of Luzon was marked by scattered epicenters. The Archipelago was very quiet during 1986, with comparatively few epicenters and limited clustering. During 1987 seismic activity increased again with the formation of a cluster between Leyte and the northeastern part of Mindanao, along the

Table 7.1 - Location and Magnitude of epicenters worldwide from 2 hours before to 16 hours after the July 16, 1990 earthquake in Luzon

US. DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY - NEIC QUICK EPICENTER DETERMINATIONS — NO. 0-204, JUL 23, 1990

UTC TIME HRMNSEC	LAT	LONG	DEP	GS MB	MAGS Msz	SD	STA USED	REGION-COMMENTS
JUL 16								
051110.4p	32.36 N	142.40 E	33N	5.0		0.8	9	S OF HOHSHU, JAPAN
055628.3s	13.374N	91.162W	33N	4.7		1.4	20	NEAR COAST OF GUATEMALA
071225.4	24.276N	121.816E	33N	5.1	4.0	1.0	21	TAIWAN
072635.9	15.675N	121.257E	36	6.7	7.7	0.9	151	LUZON, FHILIPPINE
	ISL. Mo=8.0*10**20 Nm (PPT). At least 862 people killed, more than 3,000 people injured and severe damage and landslides in the Baguio-Cabanatuan-Daguapan area. Large fissures were observed in the epicentral area. Damage also occurred in Bataan Province and at Manila. Felt (VII RF) in the Manila area, (VI RF) at Santa and (IV RF) at Callao Caves.							
083533.9s	16.299N	120.871E	33N	5.4		1.4	28	LUZON, FHILIPPINE ISL
084358.7p	15.62 N	121.29 E	33N	4.9		1.6	7	LUZON, FHILIPPINE ISL
085023.4	16.479N	121.041E	33N	5.1		1.0	28	LUZON, FHILIPPINE ISL
091608.5s	16.407N	120.976E	33N	5.2		1.4	21	LUZON, FHILIPPINE ISL
092909.2	16.455N	120.400E	33N	5.7		1.0	47	LUZON, FHILIPPINE ISL
093516.2p	16.96 N	120.27 E	33N	4.9		0.7	8	LUZON, FHILIPPINE ISL
093923.7	16.498N	120.935E	33N	5.7		1.3	32	LUZON, FHILIPPINE ISL. Felt (II RF) at Callao Caves.
100814.4	36.266N	141.328E	33N	5.1		1.0	44	NEAR E COAST OF
	HONSHU, JAPAN. Felt (III JMA) at Mito and (II JMA) at Choshi.							
101257.4	9.215N	125.477E	33N	5.2		1.2	38	MINDANAO FHILIPPINE ISL
102424.7	16.467N	120.962E	33N	5.1		1.4	28	LUZON, FHILIPPINE ISL
121836.9	16.067N	121.01E	33N	4.8		0.7	11	LUZON, FHILIPPINE ISL
123510.7	39.344N	141.965E	61	4.9		0.8	22	HONSHU, JAPAN
130242.6s	15.883N	121.125E	33N	5.5		1.3	31	LUZON, FHILIPPINE ISL
130716.8s	59.152N	151.897W	118p			0.8	11	KENAI PEN, ALASKA. Felt (III) at Homer
133117.2	16.434N	120.320E	33N	5.6	5.4	1.2	37	LUZON, FHILIPPINE ISL
145136.2	32.520S	70.096W	106D	5.5		1.0	62	CHILE-ARG BDR REG.
	Felt (VI) at Calera., Illapel, Los Molles and Salamanca; (V) at Cabildo, Combarbala, La Ligua, Los Andes, Valle Nevado and Vicuna; (IV) at Santiago and Valparaiso; (III) at La Serena and (II) at Talca, Chile. Also felt (IV) at Mensoza, Argentina.							
150428.2	16.525N	120.248E	33N	5.5	4.5	1.2	32	LUZON, FHILIPPINE ISL
161934.3s	16.408N	120.366E	33N	5.5		1.2	33	LUZON, FHILIPPINE ISL
165338.5s	15.804N	121.305E	33N	4.7		1.2	7	LUZON, FHILIPPINE ISL
18037.3s	28.511N	56.979E	33N			0.2	7	SOUTHERN IRAN
191458.7	24.329N	121.813E	75a	5.5		1.0	50	TAIWAN. Felt at Taipei
194525.3s	16.437N	120.526E	33N	5.1		0.7	12	LUZON, FHILIPPINE ISL
201606.7s	16.650N	120.428E	33N	5.2		1.2	27	LUZON, FHILIPPINE ISL. Felt (III RF) at Santa
203124.7	17.518N	121.045E	33N	5.3		1.0	41	LUZON, FHILIPPINE ISL
204418.9	15.479N	121.302E	33N	5.2		1.1	20	LUZON, FHILIPPINE ISL
212621.4	16.322N	120.469E	33N	5.1		0.9	18	LUZON, FHILIPPINE ISL
224428.1n	60.012N	153.285W	145p			0.5	7	SOUTHERN ALASKA
233016.5s	36.751N	141.414E	33N			0.8	10	NEAR E COAST OF HONSHU, JAPAN

golden co usa 1990 JUL 23 12:12
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To: ISDRES::40302::BOLLET

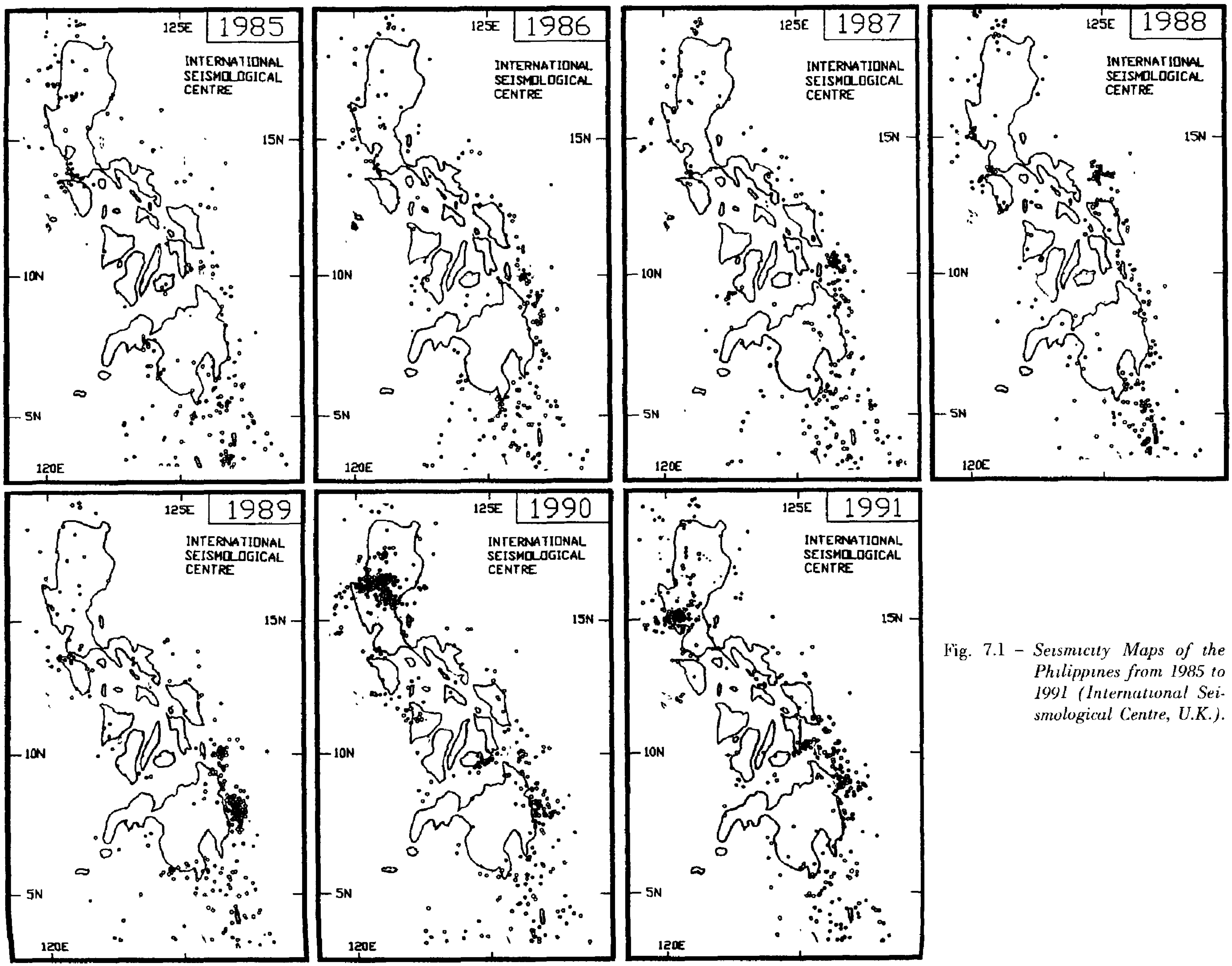

Fig. 7.1 – *Seismicity Maps of the Philippines from 1985 to 1991 (International Seismological Centre, U.K.).*

Philippine Trench. Activity continued during 1988 with a cluster east of Mayon Volcano (Legaspi). Almost no seismicity was recorded in Luzon during 1989, but two clusters formed east of Mindanao within the Philippine Trench zone. This year of relative calm in Luzon gave way to very high seismicity in mid-1990, with the formation of some major clusters in central and northern Luzon and some minor ones west and north of Mindanao Island. The abrupt change in the seismicity level started with the July 16, 1990 earthquake in Luzon.

The impressive difference between 1989 and 1990 shows that during the period of relative calm stress release must have been prevented by the presence of insuperable obstacles to movement along faults. The shearing off of these barriers required a long accumulation of stress which lasted during the whole of 1989 and half of 1990, ending with the July 16, 1990 events and numerous aftershocks during the same day and the next four days. Numerous epicenters clustered around Mt. Pinatubo in 1991.

7.3 Aftershock swarm

Figures 7.2 and 7.3 show the major features of the aftershock swarm, namely, a) the tendency of shocks to form clusters in specific areas, b) the northward trend in the formation of clusters, c) the importance of the Baguio cluster covering about 200 sq. km.

The area affected by the aftershock swarm extends for nearly 400 km, from Dingalan Bay to the northwestern tip of Luzon (Fig. 7.3). Cluster development from July 1990 through February 1991 indicates that a complex interaction occurred during this period, with contiguous blocks influencing one another and contributing to the formation of new temporary equilibrium conditions. The rate of subsurface block readjustment in Central Cordillera, based on aftershock occurrence, was critical from July 16 to July 20, 1990, both in terms of the number of tremors and the presence of some Magnitude 6 events; it then started to decrease. Figure 7.2 shows the progressive formation of clusters of epicenters between July 1990 and April 1991 while Figure 7.3 illustrates the position of clusters relative to the fault system in Luzon.

The formation of clusters (Fig. 7.3) can be summarized as follows:

a) the first, located in the southernmost part of the rupture, has few epicenters, which are broadly scattered between Gabaldon and Bongabon;

b) the second, is a slightly larger concentration of epicenters extending along and to the west of the ground rupture, between Digdig and Rizal;

c) the third, located in the Kayapa-Baguio-Lingayen Gulf area represents the largest concentration of epicenters. It broadly extends west of the ground rupture, with a decrease in the density of epicenters towards the Gulf of Lingayen. The shape and the area involved indicate a considerable activity associated with motion along major faults and sub-faults near and south of Baguio.

d) the fourth, located near Bengued City District (Abra Province), suggests that the subsurface slip induced by the July 1990 quake probably continued underground beyond Kayapa along the Abra River Fault. The progressively northern trend in seismic activity along the Digdig and Abra Faults suggests that the two faults actually form a single tectonic lineament.

e) the fifth is a minor concentration of epicenters in the area south of Pasaleng Gulf. It appeared only in 1991 (January through April), thus it is the last in the time sequence and the most northerly in terms of location. Its position suggests that the postulated underground slip motion (beyond the northern terminus of the July 1990 ground rupture) might have influenced block motion as far north as the area between Luzon and Taiwan.

The upward migration of hypocenters four days after the July 16, 1990 events is shown in Table 7.2, which covers the aftershock period July 16 - October 19, 1990 (Besana et al., 1990). Table 7.2 provides a clear indication of the depth and trend of subcrustal readjustment, based on the upward migration of hypocenters.

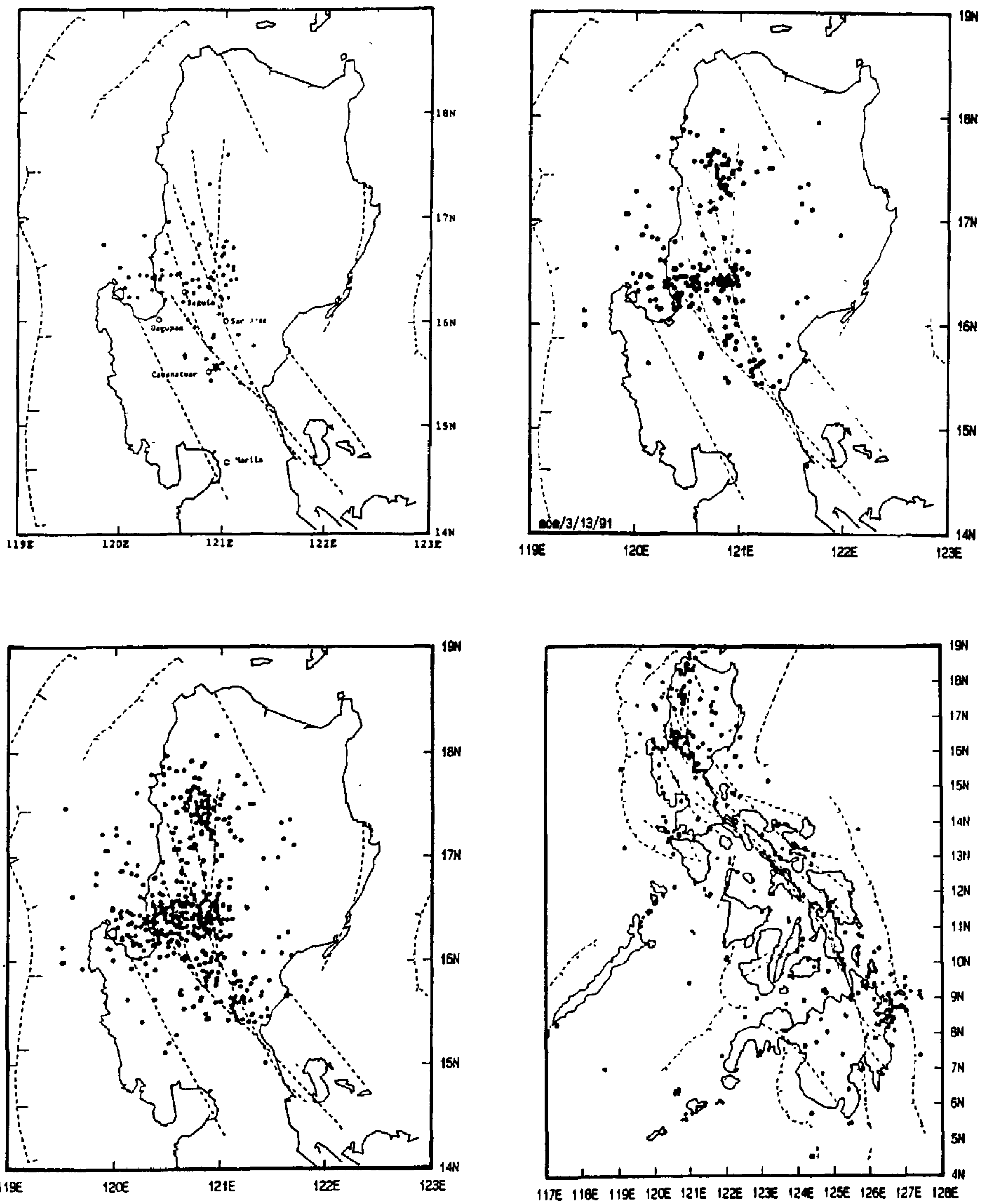

Fig. 7.2 – *Distribution of aftershocks within two weeks after the main July 16, 1990 shocks (top left), between July 1990 and January 1991 (top right), between July 1990 and February 1991 (bottom left), by Besana et al. 1990. Seismicity of the Philippines between January and April 1991 (bottom right), by PHIVOLCS.*

The five periods into which the aftershock sequence has been divided are based empirically on various factors such as the number of tremors per day, pauses of a few days between homogeneous after-shock episodes and magnitudes.

The first group (July 16-20), for instance, includes numerous shocks associated with the major events of July 16. Fifty-seven events in five days, with an average of nearly 12 shocks per day, represent the most critical episode with the majority of quakes at a depth of 32 to 33 km.

The second period, ending August 7, is characterized by a marked drop in frequency to an average of four shocks per day with the majority at depths between 1 and 10 km. Third, fourth and fifth episodes, separated by pauses of a few days almost entirely free from seismicity, are characterized by an average of 2 to 3 events per day, most of them at depths of 1 to 10 km.

A clear trend of depth of foci with time emerges: during the first five days 56% of hypocenters are located at 33 km depth and 37% between 1 and 23 km, while during the July 21 through October 19 period an average of 59% of hypocenters has already migrated to the 1 to 10 km depth range.

The definite upward migration of foci in the top 10-km crustal zone, suggests that barriers and jogs getting into a critical condition and then sheared off, were located at progressively shallower depths where confining pressure is lower.

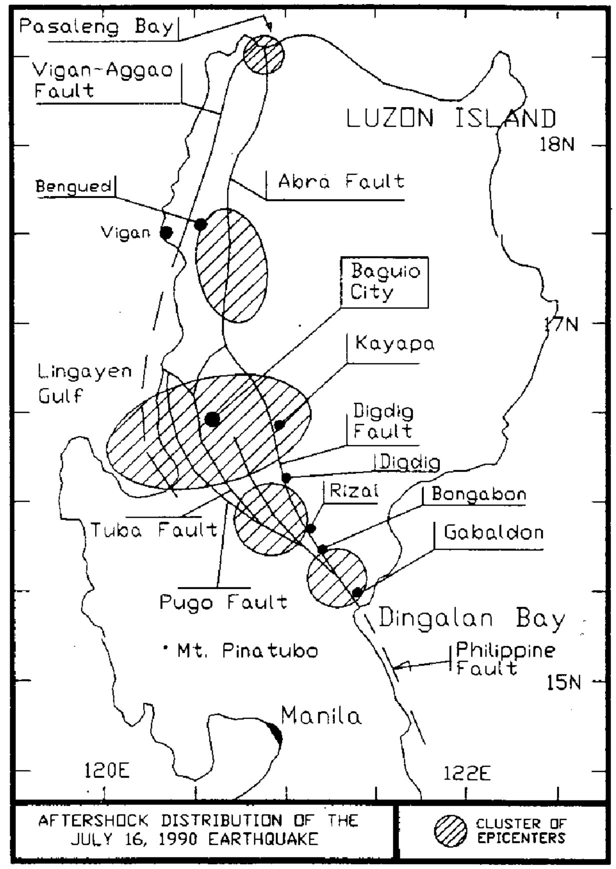

Fig. 7.3 – *Map of the clustering of aftershocks between July 1990 and May 1991.*

TABLR 7.2 - Depth distribution of hypocenters during the period July 16 - October 19, 1990

Period	N. of Events	1-10 km	11-23 km	24-31 km	32-33 km	34-59 km	67-161 km
16-20/7	57	6 11%	15 26%		32 56%	1 2%	3 5%
21/7-7/8	71	38 53.5%	18 25%	5 7%	9 13%		1 1.5%
11/8-2/9	44	29 66%	7 16%	2 4.5%	1 2%	2 4.5%	3 7%
6-28/9	50	31 62%	16 32%	1 2%	1 2%		1 2%
3-19/10	45	25 56%	14 31%	3 7%		2 4%	1 2%

7.4 Concluding remorks

Some observations can be made regarding the July 16, 1990 events and the aftershock swarm:

- the compressional regime in western Luzon persisted long after the major and minor July 16, 1990 tremors. In addition to barriers sheared off on July 16, other obstacles and undulations were progressively eliminated as soon as their stress condition became critical.
- the upward migration of hypocenters from 33 to between 1 and 10 km depth is indicative of block readjustment having been virtually completed in a few days at the higher stress levels at 32-33 km depth.
- the location and timing of the Bengued and Pasaleng Gulf aftershock clusters suggest that the ground rupture proceeded underground northward along the Abra Fault;
- the seismic quiescence in 1989 (and probably part of 1990) in contrast to the high level seismicity of July-December 1990 suggests that seismicity level variations may be significant. An investigation on «seismic gaps» and their implications could provide clues to future strong earthquakes.
- the trend and timing of the crustal readjustment in Luzon (induced by the July 1990 earthquake) is thought to have caused the intrusion of molten rock into the fractures below Mount Pinatubo and the warming up of Mount Taal (south of Manila) during 1991.