CHAPTER 8

THE ERUPTION OF MOUNT PINATUBO IN 1991

8.1 Introduction

Mount Pinatubo (1,745 m altitude before the collapse of the crater in 1991) is located in the southern part of the Zambales Range, west of the Central Plain. As the highest Quaternary cone of Central Luzon, Pinatubo belongs to the Bataan Lineament, a sequence of calc-alkaline edifices, forming part of a volcanic arc several hundred km long. Figure 8.1 provides an overview of the physiography of the region with four volcanoes, namely the active Mt. Pinatubo and three dead cones nearby. Two, Mt. Natib and Mt. Mariveles, are massive and composite edifices forming the Bataan peninsula, west of Metro Manila; the third, Mt. Arayat, is an isolated cone in the Central Valley some 35 km east of Pinatubo. Most of the huge alluvial plain extending N and S of Mt. Arayat is drained by the Pampanga River, its affluents and an intricate network of minor streams and channels, all flowing into Manila Bay.

During the eruption of Mt. Pinatubo, between June 12 and 15, 1991, the volcano spewed out several cubic kilometers of ejecta, most in the form of ash. Heavy pyroclastics were deposited in abundance near the crater, while steam clouds carrying huge quantities of ash rose to a height of thousands of meters.

Part of the dust forming a mushroom cloud was directed westward by typhoon winds, and part of it was deposited over the volcanic landscape, the thickness of the cover decreasing with distance from the crater. As a result of the eruption a 10,000-square kilometer ashfall blanketed Central Luzon provinces bringing death and devastation. The part of the ash cloud driven westward soon approached the coast of Vietnam and within a month it had circled the globe, reaching the Hawaiian archipelago by July (National Geographic, May 1992).

Further havoc was wrought by the destructive power of hot and cold mudflows, or primary and secondary lahars (Indonesian), the slurry-like streams of water-saturated volcanic ejecta originating from the slopes of Pinatubo during and after the eruption. During the major explosive phase of June 1991 the monsoon downpours saturated and then mobilized the ash cover thus starting cold lahars; the rains also enhanced the devastating potential of primary lahars which had originated directly from the high temperature mixture of ejected ash and steam. Through the numerous streams and tributaries dissecting the volcanic landscape, the gray mixture flowed down the natural drainage system, finally reaching the flatlands, engulfing villages, filling depressions and causing huge devastation.

Figure 8.2 illustrates the hazard zones with the circles indicating the radial distance from the crater, and the municipalities affected by the ashfall or/and by mudflows.

8.2 Geo-tectonic setting

The geology and tectonics of Central Luzon were described in Chapter 3. More detailed information on the volcanism of the region is provided here. The Philippine Archipelago is characterized by the presence of volcanic arcs (linear sequences of volcanoes) essentially parallel to subduction zones. The descent of the plates to a depth of several dozen kilometers under Luzon causes them to melt, while their collision produces block movements along faults and thus, earthquakes, as well as the mobilization

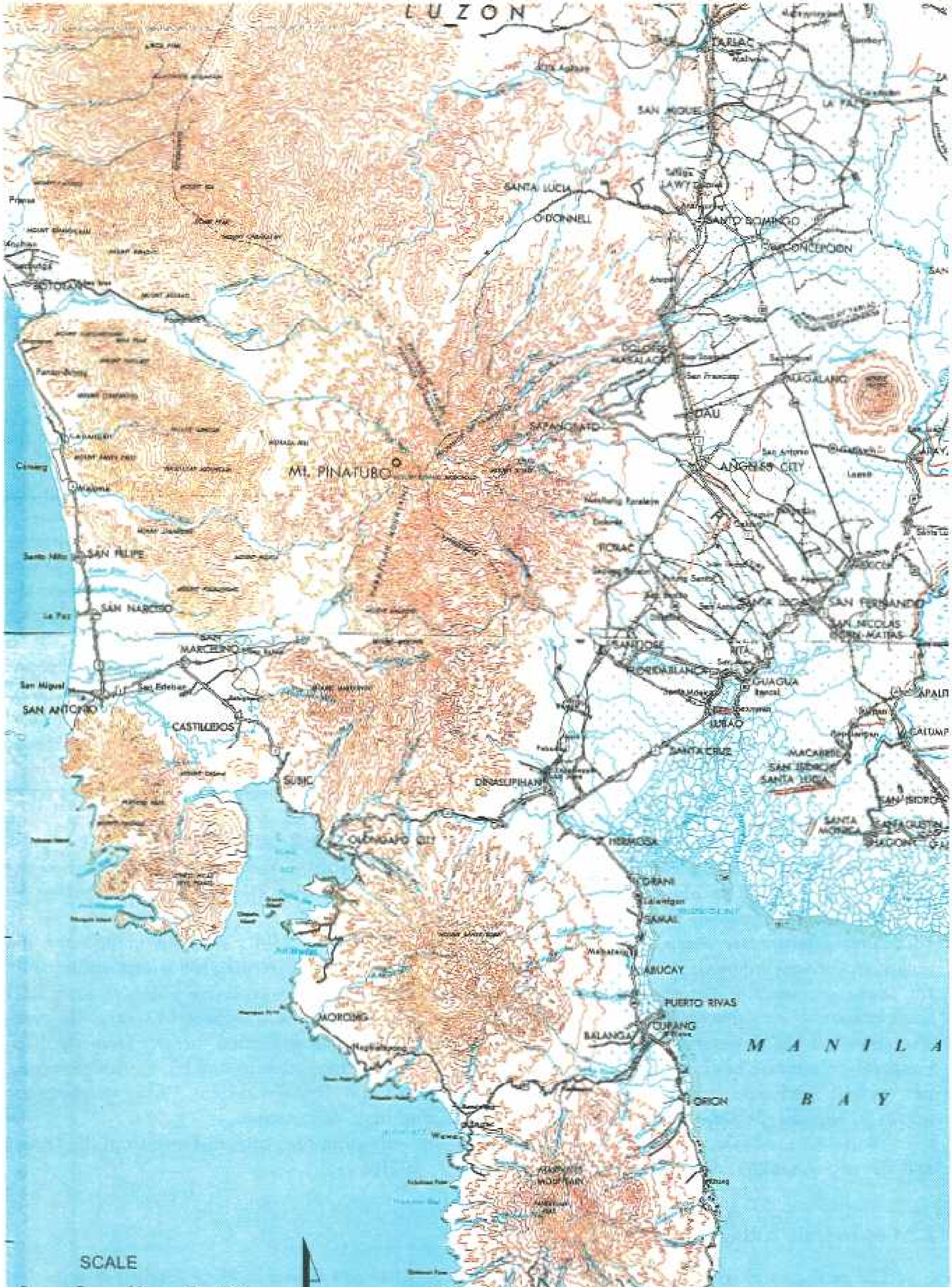


Fig. 8.1 – *Physiographic features of Mount Pinatubo and nearby volcanoes.*

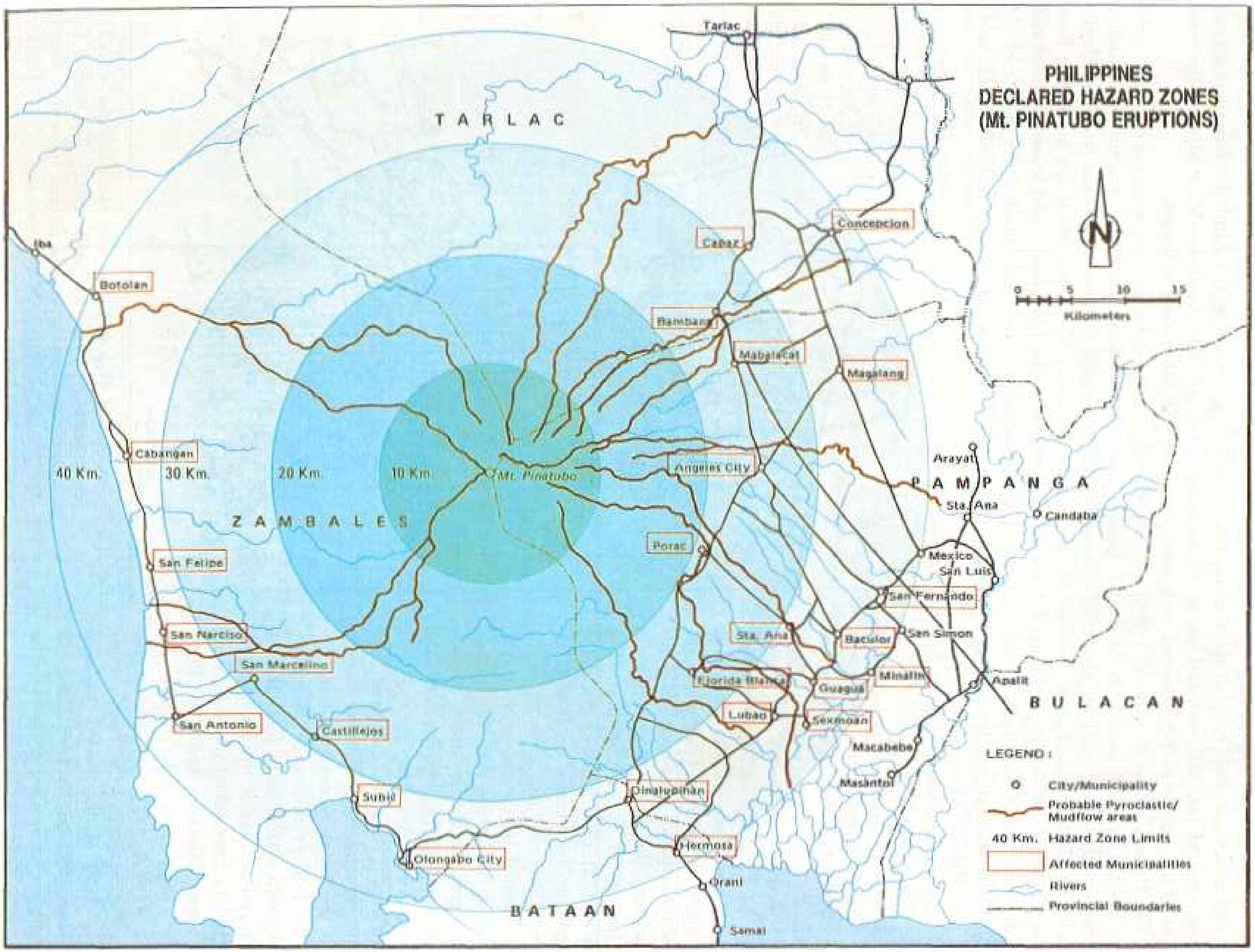


Fig. 8.2 – *Map of declared hazard zones due to lahars activated by monsoon rains (ADB, 1991b).*

of the molten rock formed near Benioff Zones. Under these conditions the molten material can find its way upward through fractures to the ground surface often producing powerful eruptions.

Of the four arcs that occur in the Philippines along mobile subduction zones, the West Luzon Volcanic Belt is of particular importance; Mount Pinatubo is situated in the northern part of this arc, known as the Bataan Lineament.

The mountain chain west of the Central Plain, commonly known as the Zambales Range, is actually composed of two different and partly overlapping sub-units. The Zambales Mountains in the west consist of an ophiolitic N-S oriented rock complex about 130 kilometers in length.

The Bataan orogen is a line of recent volcanoes bordering the ophiolitic sequence on the inner side. From Mount Pinatubo, which is the major, highest and northernmost composite structure, the line of volcanoes strikes southward for about 320 kilometers, at an average distance of 100 km from the Manila Trench. The Bataan Lineament also includes the extinct volcanoes Natib and Mariveles on Bataan Peninsula. The bold dotted line in Figure 8.3 shows the location of the Lineament, which has 27 vents and includes huge calderas, strato-volcanoes, isolated and composite cones, and minor vents (Wolfe et al., 1983). Figure 8.4, an enlargement of the box in Figure 8.3, illustrates the tectonic features of this area.

The Bataan Lineament extends southward beyond the Verde Island Strait. Its products are calc-alkaline and its activity was mainly explosive (see also Chapter 3), the arc being associated with subduction along the Manila Trench. The lineament is still partly active, as shown by recent events of Pinatubo and by the more than ten eruptions of Mt. Taal (Fig. 8.4) since 1965. The 1754 and 1911 phreatomagmatic eruptions of Taal are among the most catastrophic in the history of the Philippines. The former event significantly altered the morphology of Taal's caldera (Hargrove, 1991) by the closure of its wide channel to the sea with a barrier of pyroclastics and the consequent gradual change from a salt-water bay in the caldera into the present fresh-water lake.

Mount Pinatubo original andesitic products later became dacitic, while the most recent eruption, before the 1991 events, consisted mainly of plagioclase-rich tuffs (ignimbrite). The major activity of the lineament is believed to have taken place between the lower Miocene and the Pleistocene (Appendix A). Figure 8.5 shows some recent volcanic eruptions along the margins of the Pacific Plate region. Five of the events between 1991 and 1993, are located along the volcanic arc stretching from the Philippines to Kamchatka peninsula.

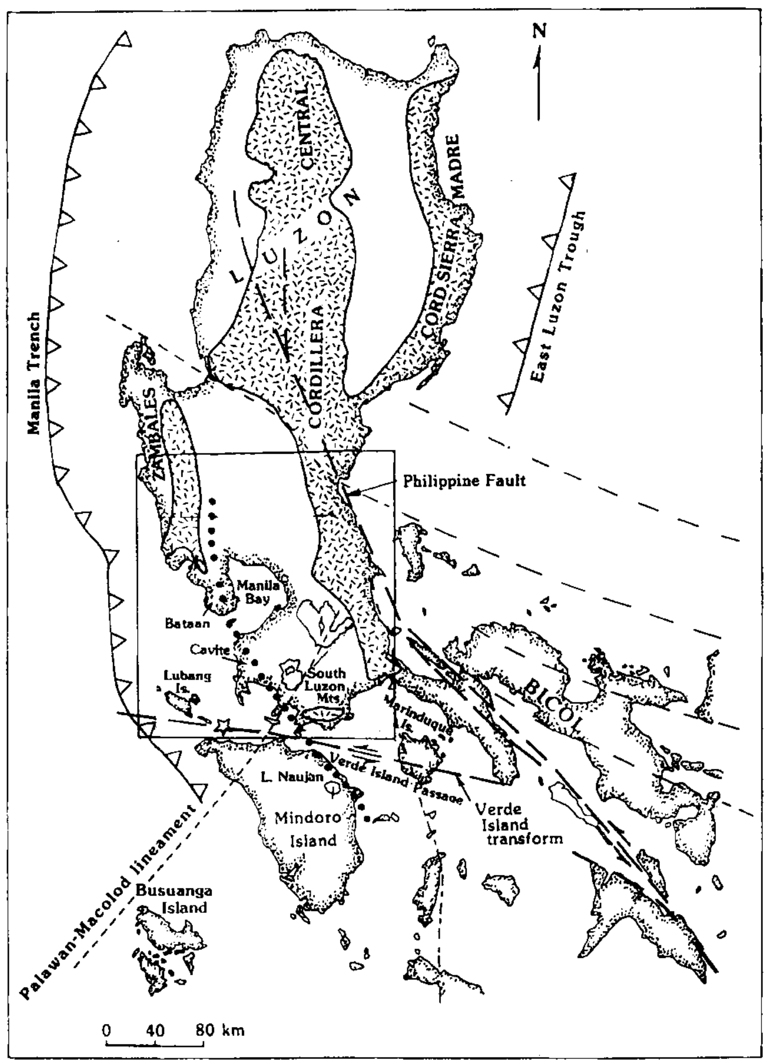


Fig. 8.3 – *Generalized Map of Luzon with the mountain ranges in dash pattern (Wolfe and Self, 1983). The dotted line indicates the location of the Bataan lineament hosting Mt. Pinatubo. Reprinted by permission of the American Geophysical Union.*

Fig. 8.4 – *Detail of box in Fig. 8.3. Location of the Neogene volcanoes and the major tectonic lineaments of Central Luzon (VIT, Verde Island Transform Fault; MF, Manila Fault; PML, Palawan-Macolod Lineament, BL, Bataan lineament), by Wolfe and Self, 1983. Reprinted by permission of the American Geophysical Union.*

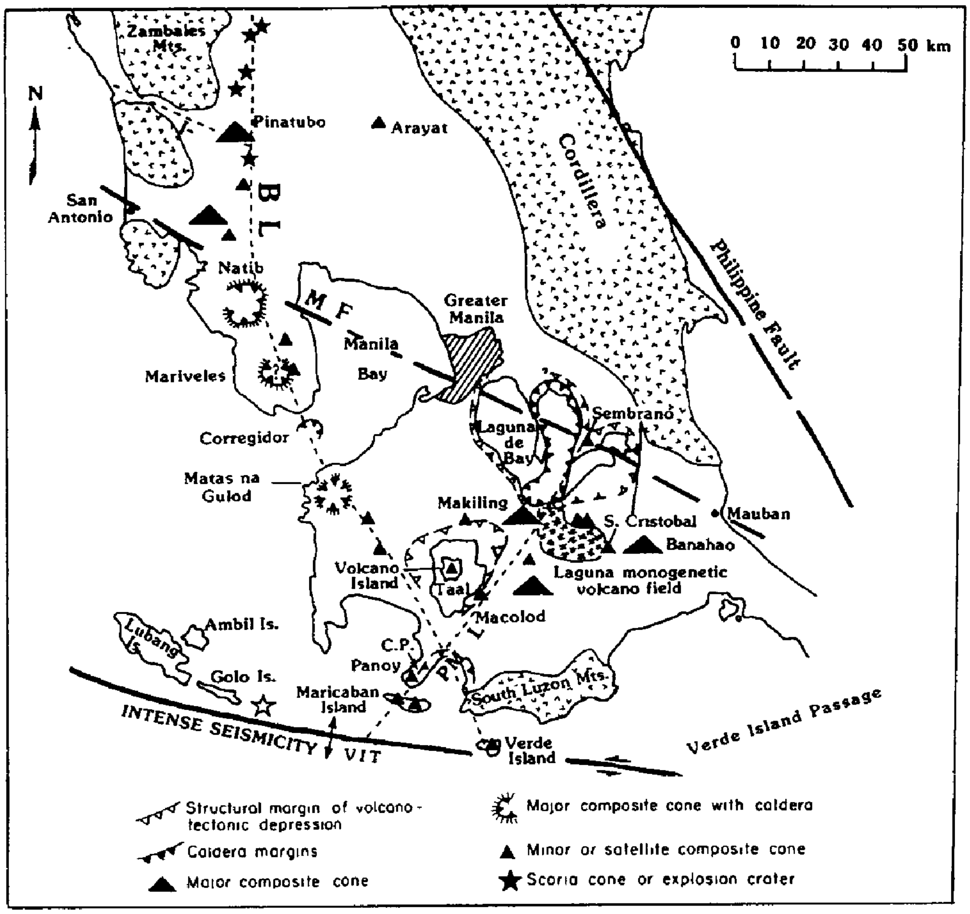
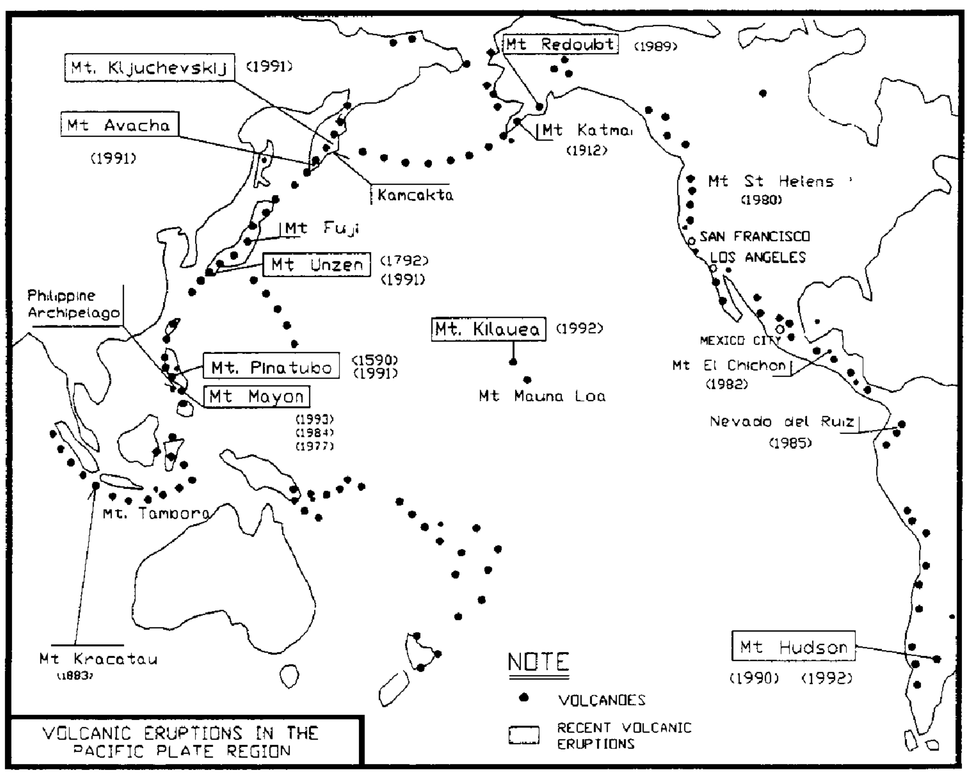


Fig. 8.5 – *Overview of eruptions by the major volcanoes in the Pacific Region during the period 1991-93.*



The June 1991 eruption of Pinatubo is attributed to the rearrangement of subsurface blocks which followed the July 16, 1990 Luzon quake. The block readjustment caused intrusion of molten rock along fractures and conduits upward into the cone.

8.3 Mount Pinatubo eruption

8.3.1 Pre-eruption signs and major explosive episodes

According to Punongbayan, in August 1990, a month after the July 16 earthquake, roars, ground cracking and a higher steaming activity of the thermal area of Pinatubo were reported to PHIVOLCS by the indigenous Aetas living around the volcano. The response team attributed the aforementioned signs to landslides initiated by the numerous aftershocks which followed the quake and by the monsoon rains, thus ignoring the possibility of an approaching eruption.

More consistent signs of Mount Pinatubo awakening after about 400 years of quiescence (according to a recent Japanese dating) arrived at the beginning of April 1991, in the form of steam clouds and ash emissions. Accompanying seismicity soon indicated movements underneath the crater and the possibility that they could turn into an eruption. Shallow-seated seismic activity, smoke mixed with ash and the emergence of a dome on June 8 persuaded government authorities to start the evacuation of the numerous members of the Aetas tribe (Para. 8.10) living on and around the volcano. In the meantime sizable carbon dioxide and sulphur dioxide emissions indicated that magma was rising along the volcanic conduit and nearby fractures (Mount Pinatubo, 1991). On June 9, moderate explosions resulted in ash and smoke reaching Clark Air Base, nearly 20 km southeast of the crater. Volcanic ejecta soon began falling at ever greater distances, gradually approaching the more densely populated areas.

A powerful explosion from Mount Pinatubo, 8.51 in the morning on June 12, 1991 created a 20 km high ash cloud which continued to ascend steadily. According to PHIVOLCS reports, the cloud moved in a northwesterly direction and obscured the sky; high frequency tremors continuously rocked the land with ever increasing intensity, while the magma dome started growing. During the day numerous explosions were reported and abundant ashfalls and ejecta reached the cities of Olongapo and Angeles, as well as villages within 20 km from the crater. As the dome became more and more dangerous, thousands living around the volcano started moving out of the hazardous areas, while ashfalls had already blanketed hundreds of square kilometers.

Another strong explosion took place on June 13 and ash fell as far away as the Zambales, Tarlac and Pampanga provinces (Fig. 8.2). Pyroclastic flows also started moving along incised valleys around the volcano reaching considerable distances, while the ash cloud had already spread over the South China Sea. On June 14 five eruptions rocked the volcano spewing gases and ash, hot lahars began cascading from near the crater, and were made more mobile by heavy rain. On June 15th, 16 explosions occurred; ejecta were spewed everywhere and numerous explosions took place in a crescendo of seismic activity until the upper edifice of the volcano collapsed forming a new crater 2 by 3 km wide (Mount Pinatubo, 1991).

Figure 8.6 shows the volcano seen from Abacan River near Angeles (top left), a few weeks after the paroxysm, and the ash cloud as of June 1991 (top right). The bottom figure shows the northwestern border of the crater after the collapse (picture taken from PHIVOLCS Observatory, upstream of O'Donnel River). Numerous hot lahars, depending on the volume of steam-ash emissions, were generated during the critical phase (isolated smoke emissions and small hot lahars were still active in September 1991)

By June 18 Manila, 110 km SE of the crater, was darkened in daytime and blanketed by half a centimeter of ash. The deposition extended far to the west and south of the volcano whitening the South China Sea waters for days. Clark Air Base, Angeles City and villages east, south and west of the crater were heavily covered by ash. There was no panic but several thousands of refugees had already abandoned the slopes around the volcano to be relocated in safer areas. During the second half of June ash clouds passed over the South China Sea and reached Vietnam and Cambodia.

By the end of the month over 500 victims were feared, numerous injured and a number of missing, and more than a million people had been affected by the devastation. Despite the risk, however, some Aetas refused to abandon their land around the volcano.

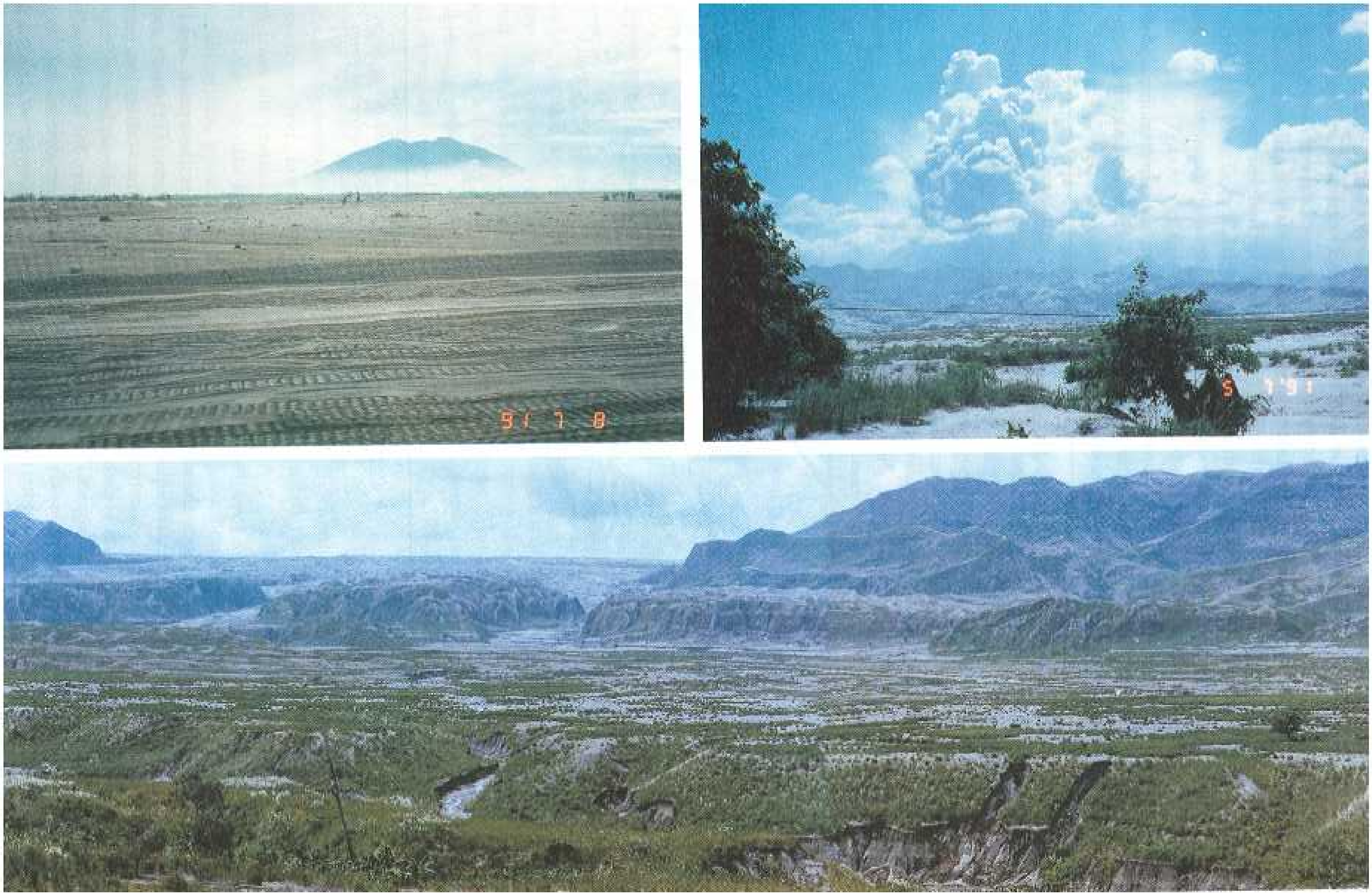


Fig. 86 – *Mount Pinatubo seen from the SE with the volcanic ash mantle in the foreground (top left), and the ash cloud (top right). The north-eastern margin of the new crater (the horizontal line) as of September 1991, after the June 15, 1991 collapse of the old structure (bottom). Along the two incisions originating from the crater (left side of the picture) hot lahars were channeled towards the initial portion of the O'Donnel River.*

Major explosive episodes are reported to have sent ashes as high as 40 km with finer particles reaching even further. Large areas of Central Plain and Zambales Provinces were at this time a scene of unprecedented destruction: a huge number of house roofs had collapsed since they were not designed to withstand the weight of several centimeters of ash blanket. The landscape and the farmland were buried under a variable thickness of ash, while human activities in commerce, agriculture and industry had come to a standstill. The drama of the homeless and jobless was the initial step of a further tragedy: farm animals were dying everywhere since food or grazing was no longer available and the agro-industrial framework of the region was entirely disrupted.

The overall volume of ejecta, including the amount deposited in Luzon and surroundings plus the finer part blown into the atmosphere, is estimated at several cubic kilometers. During site visits by helicopter huge pot-shaped valleys filled with pyroclastics were observed near the crater, with an estimated thickness of over 100 m of ashes and other ejecta.

Figure 8.7 (based on a Hazard Map of Mount Pinatubo as of July 1991, prepared by Punongbayan and Rimando of PHIVOLCS) shows isopachs of the ashfall, the location of pyroclastics and lahar (mudflow) areas around the volcano. Pyroclastic flow deposits radiate from the crater along major incisions, while isopachs of airfall ash indicate the thickness of the deposited material. Due to the westward direction of typhoon Diding in June 1991 larger quantities of ash accumulated over the Zambales side of the volcano. Finally, in black, the map shows lahar prone areas, already reached by mudflows by the end of July 1991.

After the mid-June paroxysms of the volcano, some gas and ash emission and minor seismicity continued during July through September, although at a lower intensity.

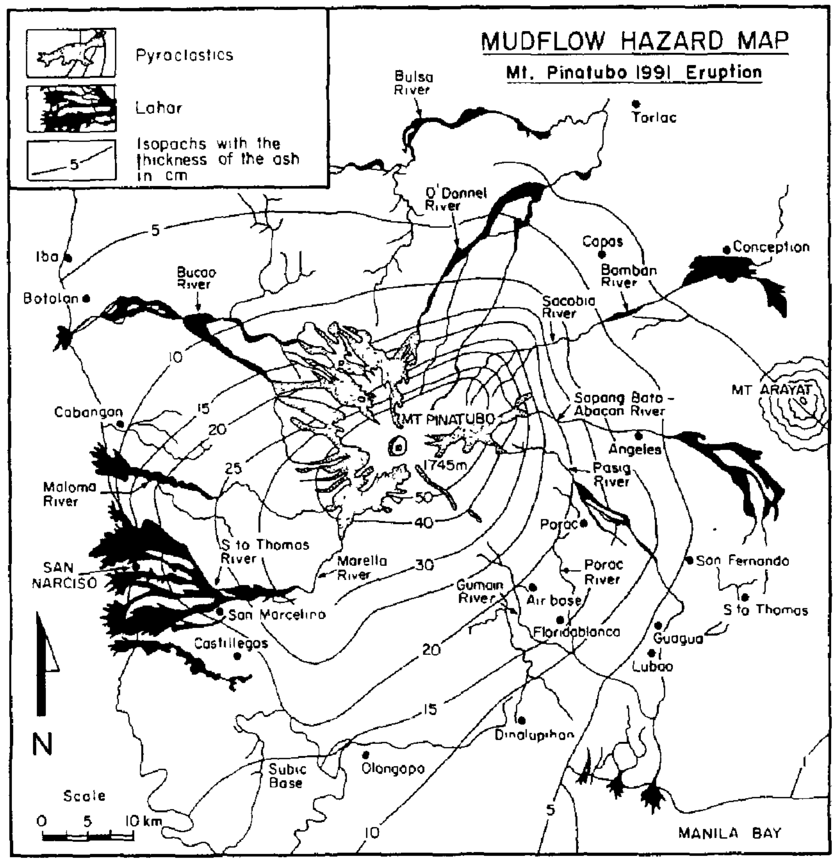


Fig. 8.7 – *Mudflow Hazard Map of Mount Pinatubo, showing isopachs of the ashfall and lahars as of July 1991 (adapted from Punongbayan and Rimando, 1991).*

8.3.2 Some considerations on the eruption and related effects

Major primary effects of the eruption were the deposition of heavy ejecta near the crater and the blanket of ashes covering an area of over 10, 000 square kilometers in Central Luzon. The entire environment sufferd badly from the eruption and disastrous consequences affected human activities, fauna and flora. Steam, sulphur dioxide, other gases and fine ash were dispersed into the atmosphere affecting the earth's climate and the ozone layer in the tropics. More dangerous and destructive for human activities and structures were lahars: mudflows of poorly-consolidated volcanic ashes mobilized by heavy rain. With a wet-concrete consistency, the slurry-like mixture began moving downslope, through minor and major streams, finally reaching the plains.

Overlapping old lahars were discovered in various parts of the flat land around the cone, as a consequence of the riverbank erosion. West of the volcano, near San Marcelino in Zambales for instance, a sequence of old mudflows was observed along Sto. Thomas River banks. The Central Plain, which is a geologic depression filled with loose Tertiary and Quaternary materials, was also shaped by the abundant products ejected by the local volcanoes and by the subsequent lahars.

By September 1991. sixty-two municipalities and two cities in the provinces of Zambales, Tarlac, Bataan and Pampanga were declared calamity areas. Of the 581 casualties 200 died as a direct effect of the eruption, 77 were victims of lahars, 211 lost their lives due to exposure to disease and malnutrition at evacuation centers and 93 died from other causes. Among the casualties in evacuation camps most were Aetas. Over one million people were affected by the eruption and its aftermath.

About 80,000 hectares of fertile land were buried under the ash blanket or lahar in the provinces of Zambales, Bataan and Pampanga (Fig. 8.2). Heavy damage was inflicted on the irrigation system, water and electricity distribution services, infrastructure in general and roads and bridges in particular. In the major industrial cities of Angeles and Olongapo most of the commercial and industrial activities were disrupted, while Clark Air Base was evacuated and later abandoned.

A number of critical lahar periods, associated with major explosive phases and tropical storms, occurred during the June-September monsoon season. According to The Manila Times (July 2, 1991), «steaming earth and boulders the size of refrigerators roared down the banks of the Porac River last Sunday (June 30), burying six Pampanga villages (Fig. 8.2) and threatening six more». On July 24, 1991, according to the same newspaper, the day before «more than 60,000 people fled their homes after massive lahar loosened by the tropical storm Herming, swept through 10 rivers in Tarlac, Pampanga and Zambales». Some 5,000 others were trapped in 12 villages in Conception (Tarlac), and Air Force helicopters were sent to rescue people who had sought refuge on roofs.

8.4 Volcanic ejecta and their mobilization

8.4.1 Pyroclastics, sediment delivery in 1991-93 and gases

The main explosions occurred June 12 through 15, 1991. A huge quantity of pyroclastics, including blocks, pumice and ashes, accompanied the numerous gray clouds which reached more than 30 km above the crater. Pyroclastic flows, channelled along narrow steep-sided valleys around the cone, soon filled river channels. Abundant ashfalls occurred during the days of the most violent explosions, blanketing the provinces of Pampanga, Zambales and Tarlac. The upstream segments of major rivers (Fig. 8.7) originating near the crater (Sacobia-Bamban, O'Donnel, Bucao, Maloma, Sto. Thomas, Gumain, Porac and Pasig), received huge quantities of pyroclastics, while topographic depressions and gullies were filled by falling eruption products and flows. By June 15, with the collapse of the crater after 16 strong explosions and the blanketing of the entire volcanic edifice and its surroundings, Mount Pinatubo entered a relaxing phase. Through July-September, the volcano cooled down while the numerous lahars activated by monsoon rains ravaged the flat land. By October 1991 the major eruption of this century in Luzon was over, but death and destruction dominated the whole environment at a distance of tens of km from the crater.

Based on data from various sources (Janda et al., 1991, Pierson et al., 1992) and on the author's considerations, pyroclastic flow deposits around Pinatubo amounted to over 7 cubic kilometers. Of this volume the quantity deposited in the catchment basins of the 5 major rivers was evaluated at 6.65 cubic kilometers (Table 8.1) and the quantity of erodible material with the potential to turn into lahars was estimated at 3.44 cubic kilometers.

The volume of sediments carried by lahars during the 1991, 1992 and 1993 rainy seasons reached 0.8, 0.55 and 0.5 cubic kilometers, respectively. The residual volume (1.86 cu. km) is expected to turn into lahars during the next years, depending on the intensity of seasonal rains. Although the revegetation and the natural compaction of ashes may partly reduce the 1994-98 mudflow hazard, the risk remains high.

TABLE 8.1 - Potential lahar sediment volumes for major Pinatubo drainages, and the sediment delivery rates from 1991 to 1993 (mcm: million of cubic meters). After *Pierson and others*, 1992

WATERSHED	Volume of pyroclastic flow deposits (mcm)	Volume of erodible PF (mcm)	Erodible pre-eruption sediments (mcm)	Potential Lahar sediment volume (mcm)	1991		1992		1993 **		Lahar deposits to date (mcm)	%	Remaining source sediments (mcm)	%
					Lahar deposits (mcm)	%	Lahar deposits (mcm)	%	Lahar deposits (mcm)	%				
O'Donnell-Bangut-Tarlac	600	240	24	264	100	38	20	8	30	11	150	57	114	43
Sacobia-Pasig-Abacan	1,600	640	64	704	210	30	110	16	100	14	420	60	284	40
Sacobia-Bamban	*900*	*360*	*36*	*396*	*100*		*70*		*45*		*215*		*	
Pasig-Potrero	*500*	*200*	*20*	*220*	*50*		*40*		*55*		*145*		*	
Abacan	*200*	*80*	*8*	*88*	*60*		*0*		*0*		*60*		*0*	
Porac-Gumain	50	50	10	60	60	100	0	0	0	0	60	100	0	0
Marella-Sto. Tomas	1,300	650	65	715	185	26	195	27	125	17	505	71	210	29
Balin-Baquero-Bucao	3,100	1,550	155	1,705	250	15	230	13	250	15	730	43	975	57
TOTAL	6,650	3,130	318	3,448	805	23	555	16	505	15	1,865	54	1,583	46

* *The Sacobia-Bamban and the Pasig-Potrero Rivers shall be competing for the remaining source sediments on the Sacobia pyroclastic flow fan, with the Pasig-Potrero dominating at the moment.*

** *Again in 1994 destructive lahars from Pinatubo buried more than 1,000 homes killing at least 23 people. On 23 and 24 September (International Herald Tribune, September 26, 1994) 15 villages were ravaged in Porac and Bacolor districts (near San Fernando, Pampanga, Fig. 4.11) by sediments up to 4 m thick in some places. Based on information televised on September 25, about 60 thousand people fled their homes.*

The overall amount of materials ejected by Pinatubo during the 1991 critical phases (including the quantities accumulated on the volcanic landscape, deposited on land and sea at greater distances from the crater and dispersed into the atmosphere) is believed to be of the order of 10 cubic kilometers.

Together with pyroclastics, steam and other gases were ejected during the eruption. As an indicator of the evolving eruption phases, the sulphur dioxide content of ash clouds was estimated (Mount Pinatubo, 1991) by means of a correlation spectrometer (COSPEC), provided by the USGS. Measurements taken from May 13, suspended for a few days during the most intensive eruption phase and resumed soon afterwards, revealed that the initial emission of 2,000 tons per day of sulphur dioxide rose to 5,000 tons per day by the end of May. The consistent increase was interpreted as a result of the magma rising towards the crater, while the sudden drop to 263 tons per day by June 5, on the other hand, was taken as an indication of the magma approaching the surface and the consequent plugging of gas passages. The monitoring of sulphur dioxide emission proved to be an excellent indicator of rising magma, thus. enabling PHIVOLCS experts to forecast the most severe explosive phase, which actually occurred during June 12 through 15.

8.4.2 Composition of the ash blanket and its effects on agriculture

According to Blong's classification of pyroclastic fragments (Blong, 1984), blocks and bombs range between 25.6 cm and 6.4 cm, lapilli between 6.4 cm and 2 mm, and volcanic ash (tephra) between 2 and 0.004 mm. Mount Pinatubo pyroclastics mostly included gravel and sand-size ejecta of porphyritic biotite-horneblende quartz latite pumice (Smithsonian Institution, 1991b). The portion of heavy products was mainly found within a 10 km radius of the crater, along major incisions and depressions. The huge quantity of fine volcanic ash was mainly deposited over the landscape around the cone and surroundings and partly injected into the atmosphere.

The presence of a considerable amount of fines explains the quantity of dust dispersed into the atmosphere and circulated around the globe, as well as the numerous, destructive lahars activated by the seasonal rains. Based on analyses by the BSWM (1991) on a few samples, the ash blanket deposited around Pinatubo's slopes mainly consisted of volcanic glass; predominantly medium to coarse silt (0.06 - 0.004 mm) and the rest of fine to coarse sand (0.06 to 2.0 mm). Some scatter of results was observed and in some locations the coarse component was greater. Deposition of the ash around the cone, during various explosive episodes, was influenced by a number of factors, namely wind direction and speed, presence and amount of gases, distance from the crater, grain size of the ash and the gradient of the natural slope

The weekly bulletin issued by the BSWM (1991) indicated that except for nitrogen (virtually absent), the major plant nutrients P, K, Ca and Mg were adequate in the ash and in the near future should result in good crop yields with low fertilizer inputs. The presumably rich allophane content (Pinatubo Soilswatch, August 1991) of the ash was expected to cause some P fixation and slow down the mineralization of organic matter.

The report also suggested that the «most worrying aspect is the excessive sulphur and iron contents in a significant number of samples even though pH almost invariably ranges between 6 and 7.7». Another hazard from the ash was the high acidity (pH between 4.5 and 4.0) of the groundwater table at depths of about 1.0-1.5 m; thus drinking water drawn from shallow wells could cause health problems. These negative effects, according to the report, will not last long, and agriculture should benefit from the new inputs of volcanic material in the course of the next decades. The thickness of the ash cover is an essential feature in this respect; up to about 10-12 cm it can easily be mixed with the existing topsoil and later become a high fertility material.

8.5 The global effect of the eruption

The Pinatubo ash cloud, which was propelled into the atmosphere in mid-June 1991, circulated westward and was reported to have reached the Hawaiian archipelago by July 1991, after almost completely circumnavigating the globe.

Soon after the eruption scientists feared that the ash-gas cloud could produce a global cooling, large temperature variations in various parts of the world as well as a negative impact on the ozone layer.

The global cooling, which was one of the effects induced by the volcanic dust and gases in the atmosphere, is due to the partial reflection of the sun's radiation. The phenomenon, which can last a few years, is thought to have contributed to anomalous weather conditions and a temporary reduction of the greenhouse effect.

According to J. W. Waters (Earth, November 1991) ten billion tons of ash and gas were ejected by the volcano. Of this volume 20 million tons were estimated to consist of sulphur dioxide. The combination of this gas with water produces sulphuric acid droplets whose shiny surface reflects part of the incoming radiation from the sun, thus lowering average global temperatures. The quantity of sulphur dioxide spewed by Mt. Pinatubo was three times the quantity ejected by El Chichon (Mexixo, 1982), whose ash cloud volume, however, was reportedly evaluated at half a cubic kilometer, an order of magnitude smaller than that of Pinatubo. Recent deviations in global temperature are in good agreement with these observations. Cold weather is also reported to have followed the eruptions of Krakatoa in 1883 and Tambora in 1815.

Cited by Earth (November 1992), Alan Robock (University of Maryland) predicted the possibility of local warming caused by the altered wind circulation. Unusual episodes of high temperature occurred, for instance, in Italy during the winter between 1992 and 1993 and in other parts of the globe. In contrast, episodes of unexpectedly low temperatures were experienced in Europe in November 1992 and March 1993. Between 11 and 14 March 1993 the entire East coast of the United States, from Florida to Washington, was hit by unusually strong winds and abundant snow in the northernmost coastal zone, with loss of lives and several billion dollars worth of damage. New York State and Florida had blackouts and paralysis of activities for a few days. According to local authorities the last time a similar case was recorded in the same area was 105 years ago.

NASA researchers (Earth, November 1992 and July 1993) indicate that the Pinatubo eruption caused considerable interference with the atmosphere and with average global temperatures. Satellite observations from the Earth Radiation Budget Experiment indicate that aerosols from the eruption could result in the increase of the amount of solar energy reflected back into space by the upper atmosphere enough to lower the average global temperature by 0.5 degree C. This cooling is expected to affect some parts of the world more than others and to continue probably until 1994-95. It is still too early to say the last word on the effects of Pinatubo's ash-gas cloud on climate. Observations made so far are in good agreement with predictions, although the amount of data is insufficient for a firm conclusion on the influence of the volcanic eruption on climate.

Another feared consequence of Pinatubo's sulphuric acid droplets in the atmosphere is the reduction in the ozone concentration. Ozone-poor air, by increasing the quantity of ultra-violet radiation received at the earth's surface, can produce dangerous effects on the human immuno-defense system and DNA, crops and life in general.

According to J. W. Waters (Jet Propulsory Laboratory, Pasadena), low values of ozone in the Pinatubo sulphur dioxide cloud above tropical regions were detected by the Microwave Limb Sounder (MLS) installed in the NASA Upper Atmosphere Research Satellite. The observed low values are believed to be due to transport effects, possibly caused by enhanced uplift of ozone-poor air from below.

The uplift, in turn, could be associated with additional heating due to solar absorption by the aerosols produced from the Pinatubo sulphur dioxide. MLS data so far available lack the long-term record which would be needed to compare time periods before and after the June 1991 eruption (Froidevaux, Waters et al., 1994; Read et al., 1993).

Figure 8.8 (J. W. Waters, Scientific American, March 1992), shows comparative images of the globe before and after the eruption.

The orange strip (lower globe) is interpreted as the sulphur dioxide cloud, presently poor in ozone. This type of gas (violet color in the upper sketch) was abundant over tropical regions before the eruption, as emerges from a comparison of the global images.

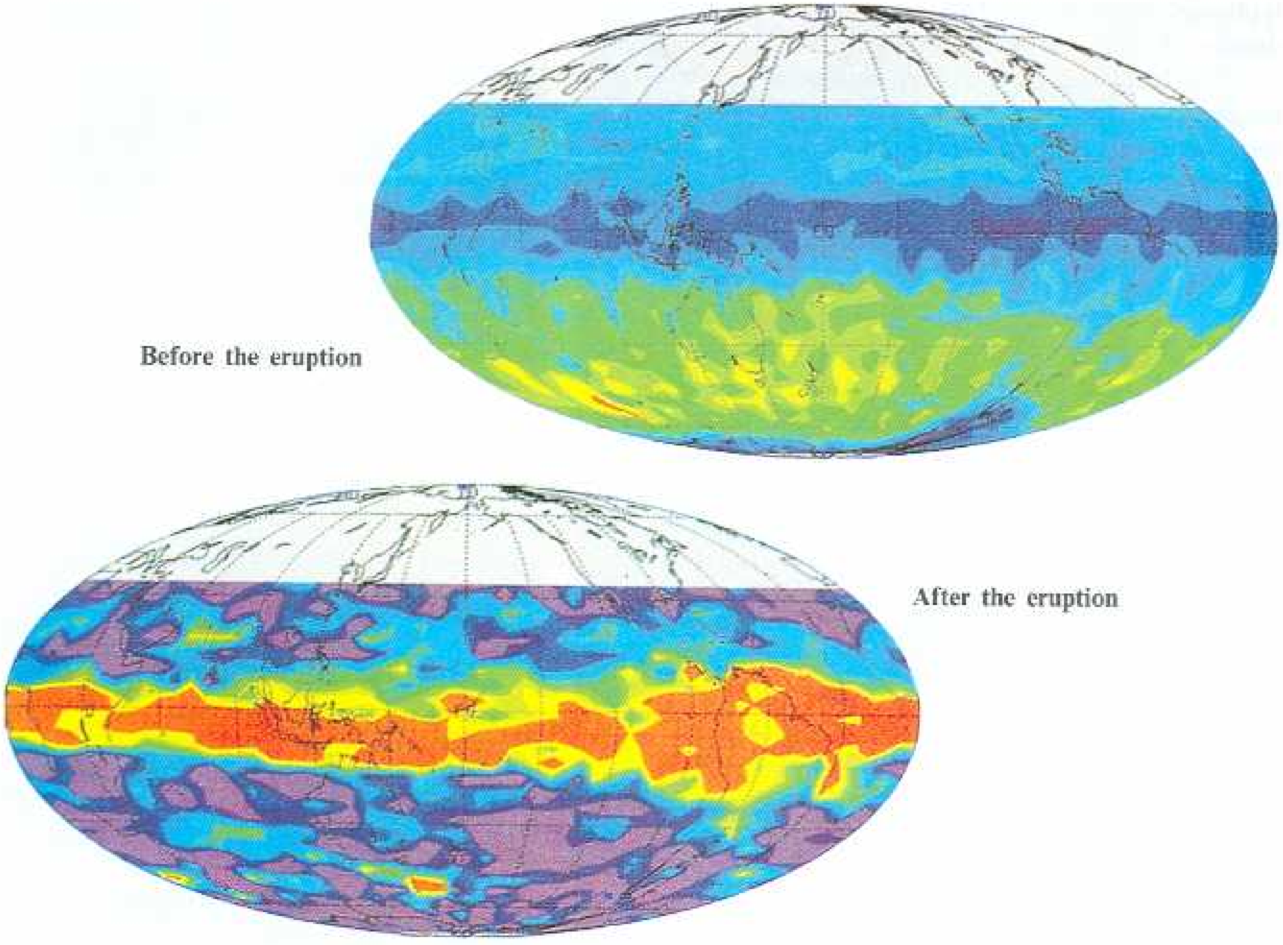


Fig. 8.8 – *Globe images before (top) and after (bottom) the eruption of Mount Pinatubo (J.W. Waters, Scientific American, March 1992). The top picture shows in violet a continuous ozone-rich strip over the tropics. In contrast the bottom picture shows in pink an ozone-poor band caused by the enhanced uplift of ozone-poor air from below, as a consequence of additional heating due to solar absorption by the aerosols produced from the Pinatubo sulphur dioxide emission (Froidevaux L., J.W. Waters et al., 1994).*

8.6 Lahars

8.6.1 Lahar initiation and development

A description of the causative factors, composition and related flow properties of lahars is essential for understanding their initiation and development consequent to the eruption. The destructive power of the lahars and their ability to alter the geomorphology are fundamental aspects of the evolution of the landscape in Central Luzon.

Devastating hot and cold lahar around Mt. Pinatubo started during the mid-June major explosive phase, triggered either by the steam condensation or by monsoon rains: in a number of cases the two processes were associated. The whole of the June-September period was marked by numerous lahars all around the volcano and they often reached the Zambales shoreline as well as the fertile flatlands of the Central Plain.

The abundant quantity of snow-like ash deposited during the eruption had no time to become compacted under its own weight nor to be partly retained by the vegetation. Mid-June rains almost immediately filled voids in the poorly consolidated ash mantle, causing the pore-water pressure build-up and the consequent decrease of the shear strength. Of fundamental importance to the initiation of lahars and to their reaching a distance of several dozen kilometers were *a*) the loose unconsolidated condition of the ash blanket, *b*) the predominantly fine grading of the ejecta, c) the abundant rains brought by