EARLY WARNING FOR THE 1991 ERUPTIONS OF PINATUBO VOLCANO — A SUCCESS STORY —

by Raymundo S. Punongbayan and Christopher G. Newhall

ABSTRACT

The success or failure of a warning system can be gauged in terms of the number of lives (and value of assets) lost to or saved from a disaster causing event. In these terms, the early warning system used at Pinatubo Volcano in 1991 can be considered a success story — the death toll of 250-300 out of the 20 000 immediately at risk was small despite the magnitude and violence of the eruption which was one of the world's biggest eruptions this century. This success can be attributed to a number of factors: early detection of the unrest, timely identification of hazards and delineation of vulnerable areas to them, successful application of state-of-the-art monitoring and surveillance techniques, accurate prediction of the most destructive phase of the eruption, timely issuance and dissemination of easily understood warnings, prompt action of key civil defence officials and disaster response workers, and timely evacuation of majority of the inhabitants at risk.

What made the Pinatubo story a classic are not only its success factors but also its near-misses — the things that could easily have gone wrong but luckily did not, which provide valuable lessons for developing warning systems in particular and volcanic risk mitigation plans in general. The positive aspects of the experience highlighted the value of the following: state-of-the-art monitoring equipment and techniques, international cooperation based on mutual respect, sustained intensive public education on volcanic hazards; active involvement of selected scientists as the designated spokespersons in awareness promotion and warning dissemination; open and speedy communication lines between the science people on one hand and the civil defence officials on the other; and good relations between scientists and the media. The near-misses or potentially negative aspects of the experience underscored the need to conduct geologic data base studies and hazard zonation on all active volcanoes long before the onset of unrest. We were lucky because Pinatubo gave us sufficient lead time to conduct reconnaissance geological studies and mapping of deposits of its past eruptions, thus enabling us to forecast the life-threatening hazards when it decided to erupt and to warn/educate concerned sectors into taking appropriate protective actions. We know that we will not always be as lucky. Hence, efforts will now be focussed on detailed studies and mapping of the unmonitored active volcanoes and on conducting in communities-at-risk an Pinatubo education campaign that would erode their indifference, scepticism and hostility to long-term action plan for volcanic disaster mitigation.

1. INTRODUCTION

Ideally, for a nation to effectively minimize or prevent disasters from volcanic phenomena, it must be able and willing to: 1) identify its high-risk volcanoes; 2) assess the hazards posed by these volcanoes, and delineate the areas likely to be affected by these hazards in hazard zonation maps; 3) monitor and forecast/predict the eruptions of these volcanoes; and, based on the outputs of these three activities; and 4) adopt measures or take actions that would reduce potential losses to volcanic hazards, such as: a) the formulation and strict implementation of land use and development plans as constrained by major volcanic hazards; b) relocation of communities at risk; c) emplacement of structural protection measures; and d) putting in place contingency plans and volcano emergency response. These four volcanic disaster mitigation components require two major sets of people and activities: the scientists on one hand to do the first three, and on the other the concerned policy makers, disaster management officials/organizations and endangered communities to do the fourth. The scientific findings of the former must be communicated effectively to the latter who. in their turn, plan and implement appropriate mitigation measures and actions The chain linking these two sets of people and activities, ensuring that scientific findings are translated into concrete loss reduction/prevention actions is — the warning system. Each link in the chain — monitoring and forecasting, warning message formulation, transmission and response to warning — is important; any weakness or failure in one component could render the whole system ineffective in preventing or averting volcanic disaster.

The 1991 Pinatubo Volcano eruption experience can be considered a warning system success story. The unrest was diagnosed early enough, the hazards were identified and the areas vulnerable to them were delineated based on interpretation of geologic record of the volcano's past eruptions, the most destructive phase of the eruption was predicted, timely warnings were issued, the disaster response machinery was mobilized, and endangered populations were evacuated on time. Thus, all except about 250-300 of the more than 20 000 dwellers in the areas overrun by the destructive agents unleashed by Pinatubo's climactic 12-15 June eruption, escaped certain death. This death toll is small considering that the magnitude and violence of the eruption made it one of the world's largest this century.

What makes the Pinatubo story a classic are not only its success factors but also its near-misses — the things that could easily have gone wrong, but luckily did not. These provide valuable lessons for developing warning systems in particular and volcanic risk mitigation plans in general. We keep discovering more and more of these "lessons" each time we recall and retell the Pinatubo story. So we shall keep recalling and retelling the story until we exhaust its treasure of lessons.

The Pinatubo story recounted in this paper shows how the warning system evolved as scientists, disaster response officials and workers, and the endangered inhabitants responded or acted in each scene of the unfolding Pinatubo Volcano drama. For additional information on the story, see Punongbayan *et al* (1996) and Newhall and Punongbayan (1996).

2. VOLCANIC RISK MITIGATION EFFORTS BEFORE THE 1990S

Before the 1980s, the Commission on Volcanology or COMVOL, the government agency responsible for monitoring active volcanoes and forecasting their eruptions, had a reactive orientation waiting for a volcano to erupt, monitoring the activities of an erupting volcano and pulling out of the scene when the volcano stopped erupting. Volcanology, as pursued then by COMVOL, had been mainly done by identifying volcanoes with short repose periods and constructing one or two monitoring stations on their slopes. No attention was given to conduct volcanogeological mapping of the monitored active volcanoes and generate volcanic hazards zonation maps, nor were there attempts to map areas impacted by volcanic hazards from a volcano that just erupted. Hence when COMVOL was re-organized into the Philippine Institute of Volcanology and Seismology (PHIVOLCS) in 1984 and transformed into a research and monitoring body, the latter only inherited volcano monitoring stations on five active volcanoes with short repose periods and growing populations (and therefore high-risk), namely Mayon, Bulusan, Taal, Canlaon and Hibok-Hibok.

During the 1980s, PHIVOLCS started upgrading and expanding the monitoring network with the addition of a sixth permanent station at Mt. Banahaw. Also initiated was a long-term program of basic studies on these six monitored volcanoes and Iriga Volcano, another known active volcano. These studies were aimed at generating information for deciphering past eruptive behaviour, understanding current behaviour and making long-term forecasts of the volcanoes' activities. Hazard assessments and zonation were also conducted on these volcanoes and the hazard zone maps produced have been disseminated to concerned land use and development planners, policy makers and local leaders of endangered communities. However, the results of these hazards assessments and our long-term (looking years to decades ahead) forecasts and warnings have been largely ignored or met with scepticism and/or outright hostility. Long-term mitigation measures such as restricting land uses and development activities for a mere "probable" event in the not-too-distant to distant future are often unpalatable to both policy makers and citizens.

During this same decade, three of the monitored volcanoes erupted — Mayon, Bulusan and Canlaon. In these volcanic crises, our medium- to short-term forecasts and warnings were often received with scepticism. Luckily, with the exception of Mayon's eruption in 1984, the other events were mild and of short duration thus not necessitating evacuation. During the Mayon Volcano 1984 eruption, the respondents to a post-eruption survey claimed that they evacuated more on the basis of their own perception of the volcano's activity than on warnings from government and media sources (Tayag *et al*, 1985).

Of the 220 or so Quaternary volcanoes in the Philippine Archipelago, we have classified as active the 22 that have erupted during historic time (or within the past 500 years) and those with no reported eruption during historical time but which showed evidence of having erupted during the last 10 000 years. Pinatubo Volcano is one of the active volcanoes with no historical eruption but was classified as such (Punongbayan 1987) on the basis of the youngest age yielded by radiocarbon dating of charcoal fragments from one of its pyroclastic flow deposits: 650 + 80 radiocarbon years (Ebasco Services Inc, 1977). Parker Volcano in southern Mindanao was added to the list in 1995 as collected charcoal fragments from its deposits yielded a carbon-14 date of 250 years.

In view of the limitations of PHIVOLCS monitoring capability and the priority given to volcanoes with short repose periods, Pinatubo Volcano which has a long repose period was not covered by the PHIVOLCS monitoring network and because of this, the onset of its unrest was not properly documented. Pre-eruption Pinatubo Volcano used to be the home of Aeta or Negrito tribes which were scattered on the slopes of the volcano straddling the three provinces of Zambales, Tarlac and Pampanga. Traditionally semi-nomadic, these tribes thrived on kaingin, or slash and burn farming, producing mostly coffee, root crops and bananas. The Aetas consider Pinatubo as their god whom they call as Apo Namalyari. When they have a good harvest, they make offerings to Apo Namalyari in the steaming ground located on the northern slopes of Pinatubo.

3. CHRONOLOGY OF PINATUBO'S ACTIVITIES AND SCIENTIFIC RESPONSES

3.1 JULY-AUGUST 1990

On 16 July 1990, a Magnitude-7.8 earthquake was generated by the Digdig Fault segment of the Philippine Fault Zone and whose epicenter was located about 100 km northeast of Pinatubo Volcano (Figure 1). A few hours after the main shock, a small magnitude earthquake occurred about 10 km southeast of the volcano. Quakes continued to be felt around the volcano area during the following weeks. We do not know, and will probably never know, whether these earthquakes were locally generated volcanic quakes or distant aftershocks of the 16 July northern Luzon earthquake.

In early August, indigenous Aetas living on the slopes of Pinatubo accompanied by nuns of the Franciscan Missionaries of Mary, reported to PHIVOLCS audible rumbling sounds, ground cracking and increased steaming from a pre-existing thermal area. A quick response team was dispatched by PHIVOLCS to investigate the reported phenomena. After conducting a cursory investigation around the thermal area, the team reported that: "Preliminary findings indicate that the phenomenon is not related with any volcanic activity...The parameters necessary for deducing an approaching... volcanic eruption were not observed in the locality" (Ramos and Isada, 1991). The team thus concluded that the reported observations of the volcano dwellers were possibly related to a landslide that was triggered by the continuing aftershocks of the regional earthquake and the recent heavy rains in the area.

3.2 APRIL 1991

On 2 April 1991, an unusually large explosion at the volcano's northern slope, accompanied by rumbling sounds and intense new steaming from several vents, prompted the same nuns and Aetas to again call on PHIVOLCS on 3 April.

PHIVOLCS again reacted by immediately dispatched another Quick Response Team which conducted ocular and aerial observations with the assistance of the Office of Civil defence and the Philippine Air Force. The team found all the reported manifestations, as well as a fissure and new craters at the northeast end of an east-west line of steaming vents. The initial assessment of the team was that the explosion was of hydrothermal origin and from one of the steaming vents on the northern slopes of Pinatubo Volcano. The team was ordered to deploy a seismograph on Pinatubo when it failed to give a satisfactory answer to the question: "Why were the Aetas bothered

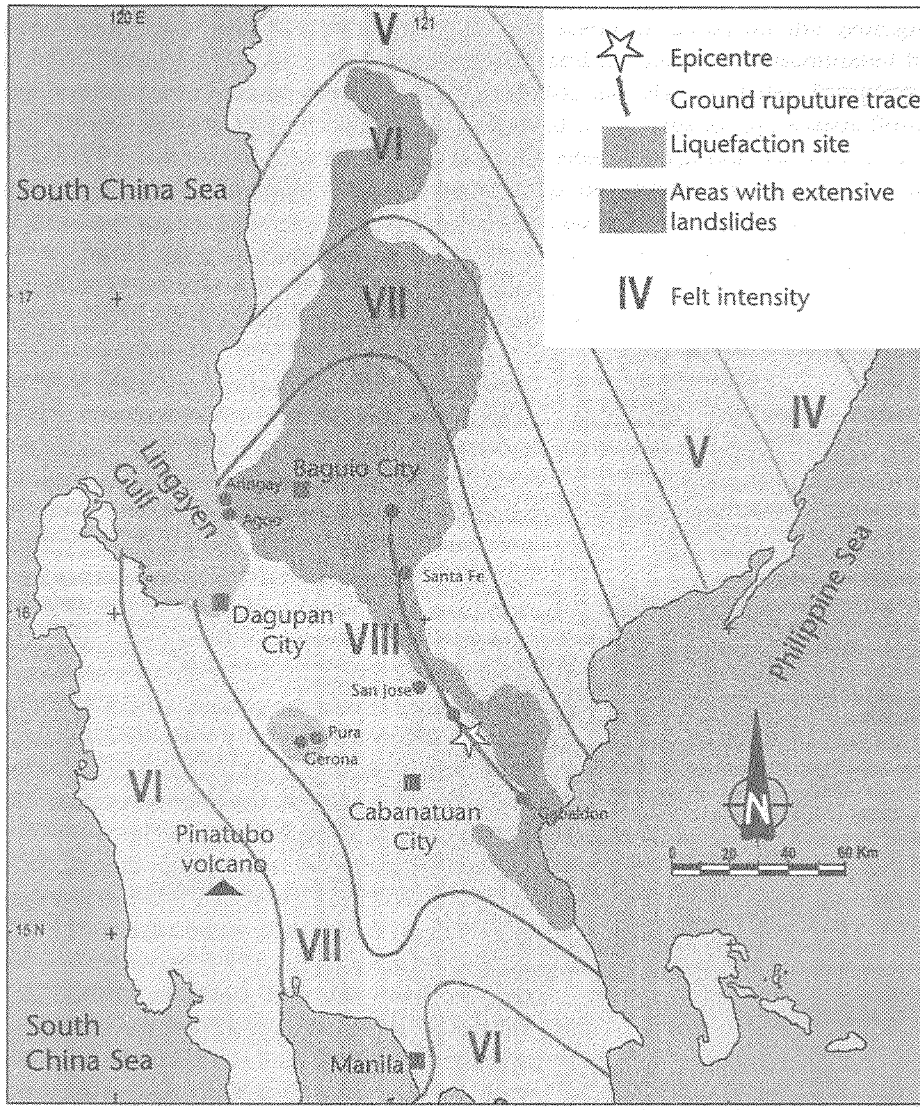

Figure 1. Map showing the location of epicentre of the 16 July 1990 M7 8 earthquake, intensity distribution and the areas affected by liquefaction and landslides.

enough to report to us the presence of new steaming vents and the unusually large explosion that occurred on 2 April ?"

A temporary seismic station was installed on 4 April at Sitio Yamut, about 12 km WNW of Pinatubo. This recorded about 500 high frequency volcanic earthquakes, some large enough to be felt at varying intensities. Convinced that Pinatubo was showing definite signs of unrest, we declared on 7 April a 10 km-radius permanent danger zone, and advised evacuation of the residents therein.

Warnings issued by PHIVOLCS at this stage took the form of volcano bulletins which contained daily earthquake counts, visual observations and assessments of the volcano's condition. Uncertain of the applicability of the alert levels previously used for the monitored Philippine volcanoes, the term "unstable" was used for describing the volcano's conditions.

The updates were prepared in the field then radioed to the PHIVOLCS central office for review and release. From the PHIVOLCS Central Office in Quezon City, these volcano bulletins were transmitted to the National Disaster Coordinating Council (NDCC) through the Office of Civil defence (OCD), the Office of the President and the Department of Science and Technology (DOST). The updates were also radioed back to volcano monitoring field stations, for local dissemination.

Additional seismograph units were later installed to augment the monitoring network. Electronic Distance Meter (EDM) stations were also set up at Sitio Yamut.

With Taal Volcano also restive at that time, we called up the United States Geological Survey (USGS) and asked for the assistance of the Volcano Crisis Assistance Team (VCAT). A three-man USGS team led by Dr Christopher Newhall arrived on 23 April.

A PHIVOLCS-USGS team was formed and with logistical support from the US Air Force based at Clark Air Base, set up a telemetered seismic network around Pinatubo and started measurements of sulfur dioxide emissions. A central station was installed at Clark Air Base on 26 April. Thus the Pinatubo Volcano Observatory (PVO) was created.

The state-of-the-art monitoring system installed at Pinatubo enabled us to track the location, size, type, magnitude and frequency of occurrence of volcanic quakes underneath the volcano on a near real-time basis. The monitoring of sulfur dioxide gave us very good clues about possible magma involvement with increasing fluxes as eruption nears.

3.3 MAY 1991

We realized that the Volcano Bulletins were inadequate media for disseminating information on the volcano's condition and activities and for transmitting advisories on appropriate precautionary actions and safety measures to concerned civil defence officials, disaster response organizations and the public. With no baseline monitoring data for the volcano, no information on precursors of its previous eruptions and practically no information about precursors of large explosive eruptions anywhere, we felt that we could not promise a specific prediction. But we thought that we could offer a simple, multi-level description of unrest. So, we designed a 5-level scheme of Alert Levels (Table 1) patterned after schemes used at Rabaul (Papua New Guinea), Redoubt (Alaska) and Long Valley (California), and in the generic model described in UNDRO-UNESCO (1985). This scheme did not technically make predictions, but simply pointed out increasing levels of unrest and corresponding decreasing assurances that an eruption would not occur within a specified period of time. The scheme was formally adopted on 13 May and Alert Level 2 was declared on the same day.

By this time, we had enough data to conclude that an eruption was entirely plausible. Our next questions were: "How large and violent would the eruption be? What areas are likely to be affected"?

Together with the USGS geoscientists, we conducted topographic map and airphoto analyses and field verification to identify hazards that could be unleashed in the event of a Pinatubo eruption. We identified three major hazards: pyroclastic flows, ashfalls and lahars. Areas likely to be affected by these hazards were delineated by analysing airphotos, topographic maps and particularly for ashfall, prevailing wind patterns. The resulting hazard zonation maps showed

Table 1

Alert level	Criteria	Interpretation
No alert	Background; quiet	No eruption in the foreseeable future
1	Low level seismicity, other unrest	Magmatic, tectonic or hydrothermal disturbance; no eruption imminent
2	Moderate level of seismicity,other unrest, with positive evidence for involvement of magma	Probable magmatic intrusion, could eventually lead to an eruption
3	Relatively high and increasing unrest including numerous b-type earthquake, accelerating ground deformation; increased vigour of fumaroles, gas emissions.	If trend of increasing unrest continues, eruption possible within 2 weeks
4	Intense unrest, including harmonic tremor and/or many "long period" (=low frequency) earthquakes	Eruption possible within 24 hours
5	Eruption in progress	Eruption in progress

STAND-DOWN PROCEDURES.
In order to protect against "lull before the storm" phenomena, alert levels will be maintained for the following periods AFTER activity decreases to the next lower level:
From Alert Level 4 to 3 Wait 1 week
From Alert Level 3 to 2. Wait 72 hours