Volcano!

Evacuation and military medical implications

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Experience with volcanic eruptions and earthquakes has given us the knowledge required to prevent casualties.

The eruption of Mt Pinatubo, the Philippines, 1991.

VOLCANIC ERUPTIONS have terrorised populations living in close proximity for thousands of years, but in the past few decades (since the Mount St Helens eruption of 1980) our knowledge of volcanoes has improved greatly. In the past, the threat of an eruption has often not been enough to persuade people to evacuate, and this complacency has sometimes led to significant loss of life. In recent years, volcanologists have refined their techniques to help better predict when it is truly "time to go."

Volcanoes and earthquakes are linked phenomena, with earthquakes often preceding volcanic eruptions. The Australian Defence Force mounted a humanitarian response to the eruption of the Rabaul volcanoes in Papua New Guinea in 1994, and to an earthquake-induced tsunami in Papua New Guinea in 1998.

This article focuses on the volcanological techniques used to monitor the Mt Pinatubo volcanic eruption in the Philippines in 1991, and outlines ADF resources used in responding to volcanic and similar natural disasters.

The regional threat

The Pacific Ocean is surrounded by a so-called "Ring of Fire"— several countries with mountainous regions bordering the Pacific and containing many active and inactive volcanoes. Russia, Japan, the Philippines, the Pacific coasts of North, Central and South America, Hawaii, and (of particular interest to Australia) Indonesia, Papua New Guinea, and New Zealand all have certain percentages of their populations at risk of earthquakes and volcanic eruptions.[1]

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Ocean ridge volcanoes continue to erupt in Iceland and Hawaii, along with scattered volcanoes in the Atlantic and Pacific. In 1992, it was estimated that there are between 500–1300 active volcanoes in the world — "active" meaning they are known to have erupted in recorded history.[1] There are also an unknown number of volcanoes with the potential to erupt given the proper stimulus.[2,3] Such was the case with Mt Pinatubo.

The earth's surface is covered by 12 tectonic plates.[4] The areas where the tectonic plates meet are areas where both earthquakes and volcanoes are likely to occur. It is estimated anywhere from 3–4 lava eruptions and 10–40 explosive eruptions occur worldwide each year.

Volcanic eruptions occurred during 2000 at the Lascar volcano in northern Chile in July; the Mount Oyama volcano on Miyakejima island, Japan, in August; the Tarvurvur volcano near Rabaul, New Britain island, Papua New Guinea, in September; and the Ulawan volcano on New Britain island, Papua New Guinea, in October.

Types of volcanoes

Volcanoes can be classified in several ways, but perhaps the most useful classification is based on how they are formed.

Rift volcanoes, such as those seen in Hawaii and Iceland, sit on a rift, ridge or cleft in the middle of their tectonic plate. The two sides of this ridge are moving in opposite directions and magma or lava comes oozing out, similar to an effusion, with little explosive activity. Twenty per cent of the world's known volcanoes are of this type.

Subduction volcanoes are more prevalent around the Ring of Fire and are thought to form when one tectonic plate "subducts" under the adjacent one, producing pressure and heat combined with sea water. This process causes rock to melt and the sea water mixes with the magma, trapping gases such as carbon dioxide and sulphur dioxide. This molten mass, under great pressure, is less dense than the surrounding rocks, so it rises, seeking a vent. As it rises it causes earthquakes and eventually finds a vent, but has to wait until enough pressure builds up to blow the plug left over from the volcano's last eruption.[2] Eighty per cent of volcanoes worldwide are of this type.[5]

Hazards

Volcanic hazards can be classified in two general categories based on distance from the volcano.

Near hazards include:

- Pyroclastic flows (hot gases emitted from the volcano which can travel at speeds up to 160–180 km/h).[2]
- Mud flows (lahars)
- Gases
  - major gas hazards are water/steam, carbon dioxide, sulphur dioxide, hydrochloric acid
  - sulphur dioxide causes a number of adverse health effects, such as headaches, fatigue, respiratory difficulties and produces *vog* (volcanic smog) and acid rain
  - minor gas hazards are hydrofluoric acid, carbon monoxide, and hydrogen disulphide
- Lightning
- Earthquakes
- Air shock waves
- Tsunamis

Far hazards include:

- Ash toxicity
- Ash-related respiratory and eye problems
- Accidents
- Transportation and communication problems
- Sewage disposal and water supply problems
- Roof collapse
- Electricity failures
- Psychological hazards[6]

Historical examples (all are subduction volcanoes)

One of the earliest known volcanic eruptions occurred as **Mt Santorini**, on the island of Thera in the Aegean Sea, blew its top in 1650 BC. This cataclysmic eruption is thought to have destroyed the Minoan civilisation and the effects of the tsunami it generated have been discovered on the island of Crete, 100 km away. Akrotiri, a city of 30 000 on Thera, was buried and is only now being excavated. This site is one of the leading candidates as the location of the lost city of Atlantis described by the ancient Greeks.[7]

Mt Vesuvius, near Naples, Italy, erupted in AD 79. In this case, earthquake activity had been noticed since AD 63. The volcano was covered with green vegetation and thought extinct by the inhabitants. Somewhere between 3300 and 16 000 people in three different towns (including Pompeii) were killed by pyroclastic flows and/or buried under 10–30 m of ash. The remains of Pompeii were not discovered until 1700 years after the event.[7] The volcano erupted again in 1944 during World War Two.

The **Kelut volcano**, on the island of Java in Indonesia, erupted in AD 1000—the oldest known volcanic eruption in Indonesia. A subsequent eruption in 1586 resulted in 10 000 deaths as a result of a lahar (mud slide). The volcano has a crater lake and 10 fatal crater lake eruptions have occurred. Drainage tunnels to control the lake level have greatly reduced the destructive impact of recent eruptions.

Mt Unzen, on Kyushu island, near Nagasaki, Japan, erupted in 1792, producing a tsunami and killing between 15 000 and 50 000 people.[5] During an eruption in 1991, 8500 people were evacuated and 43 people were killed when a pyroclastic flow changed direction.[8]

Tambora, located in the Lesser Sunda Islands, forms the Sanggar Peninsula on Sumbawa Island in Indonesia.[7] This volcano erupted cataclysmically in 1815, producing the largest known volcanic eruption in history.[9] About 92 000 people were killed, 10 000 directly by bomb impacts, tephra fall and pyroclastic flows, and 82 000 indirectly as a result of starvation, disease and hunger. The effects of this eruption were felt worldwide and resulted in the "Year Without A Summer" in 1816. Daily minimum temperatures were abnormally low in the northern hemisphere from late spring to early autumn. Famine was widespread due to crop failures.

Krakatao Island lies in the Sunda Strait between the islands of Sumatra and Java in Indonesia. Earthquakes were reported in the late 1870s. The cataclysmic eruption started in May 1883 and culminated in a massive explosion in August 1883, resulting in a tsunami which killed 36 000 people living in adjacent coastal areas. About two-thirds of the island was destroyed in the eruption.[9]

The **Mount Lamington volcano**, located near Popondetta, Papua New Guinea, erupted in 1951 after six days of precursor activity. About 3000 people were killed by pyroclastic flows and an area of 68 square miles was destroyed.[11] The eruption also produced mud flows and continued until 1956.[5]

Mt St Helens, located in the northwestern US state of Washington, experienced its first recorded volcanic activity in late March, 1980, a week after earthquakes were first felt. A cataclysmic eruption occurred on 17 May, with an avalanche followed by laterally directed pyroclastic flows. The pyroclastic flows were unpredictable and 57 people were suffocated by falling ash. Monitoring techniques used today were perfected at the time of this volcanic eruption.[7]

Nevado del Ruiz volcano, located in Colombia, South America, is a 4850m mountain with an ice-capped summit. It erupted in November 1985, producing a pyroclastic flow that melted 5%–10% of the ice cap. The resulting lahar descended on the town of Armero, about 45 km downstream, killing 23 000 people. An earlier eruption, in 1845, had produced mud slides that killed 1000 people. Geologists had warned the people living along the rivers draining the mountain that any eruption of molten or hot fragmental rock onto the summit ice could bring disaster. Although warned, no one in Armero really knew what a mud flow was; when the eruption occurred in November only a few people had evacuated the town.[12]

Hazard assessment

Geologists have developed several methods to monitor changes in active volcanoes. These methods allow them to forecast, and in some cases predict, the onset of an eruption. A forecast indicates that the volcano is "ready" to erupt. A prediction states that a volcano will erupt within a specified number of hours or days.

Methods of assessing the hazard include measuring changes in shape and elevation of the volcanic summit, patterns of earthquakes, changes in gas emission, and assessing the geologic record for evidence of previous eruptions.

Ground deformation is measured using **tiltmeters**. As magma accumulates in the shallow reservoir beneath the volcano, it exerts pressure on the overlying and surrounding rocks. The pressure causes the summit of the volcano to move upward and outward to accommodate the greater volume of magma. As magma accumulates in the summit reservoir, it causes the slope (i.e. tilt) of the volcano's flanks to increase. Geologists can use precise measurements at specific locations over a period of time to detect movements caused by magma. Other techniques, including use of global positioning satellites, electronic distance measurements using lasers and standard levelling surveys, help confirm the amount of ground deformation.

The frequency, magnitude, location and type of **earthquakes** associated with active volcanoes are used for monitoring and forecasting eruptions. For example, on a typical "quiet" day, an active volcano might have 200 low-magnitude earthquakes that are too small to be felt. In contrast, just before the onset of an eruption hundreds of earthquakes are recorded and dozens are felt near the epicentre. The distribution of earthquakes provides information about magma pathways and the structure of volcanoes. Magma movement and the onset of an eruption produce a distinctive seismic pattern called harmonic tremor. Seismologists must sort through the records of hundreds of earthquakes and determine which are related to the volcano and which were caused by man-induced or natural forces. **Seismometers**, the instruments that detect the earthquakes, are set up at numerous locations on the volcano. The data are sent by radio to the volcano observatory, where they are analysed.

Gas samples are collected from **fumaroles** (small vents from which volcanic gas escapes into the atmosphere) and from active vents. The composition of the gas or a change in the rate of gas emission provides additional information on what is happening inside the volcano. For example, an increase in the ratio of carbon to sulphur can be used to indicate the arrival of a new batch of magma at the summit reservoir. The amount of sulphur dioxide released by the volcano can be measured indirectly by a **correlation spectrometer** or COSPEC. The spectrometer compares the light coming through the volcanic plume to the known spectrum of sulphur dioxide. Typically, as an eruption begins, the amount of sulphur dioxide emitted doubles, which can have a variety of adverse health effects.

From the **geological record** of the volcano's past eruptions, an understanding of potential hazards during eruptions can be constructed. From this information, a hazards map can be drawn depicting composite "typical" and "worst case" scenarios.[13,2]

Five-level warning scheme for volcanic eruptions

Alert level	Criteria	Interpretation
No alert	Background levels of seismic activity, quiet	No eruption in foreseeable future
1	Low-level seismic activity, fumarolic or other unrest	Magmatic, tectonic or hydrothermal disturbance; no eruption imminent
2	Moderate level seismic or 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 earthquakes,* accelerating ground deformation, increased vigour of fumaroles, gas emission	If a trend of increasing unrest continues, an eruption is possible within two 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

*B-type volcanic earthquakes: These earthquakes originate usually in and adjacent to active craters at extremely shallow depths. The magnitudes are generally extremely small. The earthquake motions consist mainly of vibrations, with periods in the range of 0.2 sec. to 1.0 sec.

Finally, the accumulated data about the volcano's state of unrest can be translated into a simple, **five-level warning scheme** (see Box) to which civil defence and community leaders can key an easily understandable "ready, set, go" plan for evacuation and beyond.[11-14]

Mt Pinatubo

Mt Pinatubo, an 1800 m composite subduction volcano, had not erupted in recorded history before 1991. It is located on the main island of Luzon, in the Philippines, 12–15 km from the United States Air Force Clark Air Base to the east and 40 km from the United States Navy Subic Bay Naval Base to the southwest.

On 16 July 1990, a 7.8 Richter magnitude earthquake struck central Luzon Island, with its epicentre about 100 km from Mt Pinatubo and Clark. A total of 1283 people were killed and 2786 injured as a result of the major tremor.[15] Personnel from both bases mounted major disaster response and humanitarian relief operations.

In August 1990, rumbling sounds, ground cracks and a landslide covering 2–3 hectares on the upper northwest face of Mt Pinatubo were reported to the Philippine Institute of Volcanology (PHILVOLCS).[13] On 3 April 1991, new rumbling sounds, earthquakes, explosions and the opening of new vents or fumaroles were reported on Mt Pinatubo.

A seismograph installed by PHILVOLCS revealed 500 earthquakes per day. A precautionary evacuation of 5000 tribespeople from villages 10 km from the summit was ordered.

On 10 April, PHILVOLCS sought help from the Volcano Disaster Assistance Programs' Volcano Crisis Assistance Team of the US Geologic Service. The team arrived on 23 April and set up on Clark Air Base, taking advantage of the air, logistical, housing and communication support the base provided.

On 7 May, seismometers indicated two non-specific centres of earthquake activity, and on 13 May the geologists used the COSPEC from a helicopter, and measured 500 tons/day of sulphur dioxide emitted. This confirmed the cause of the seismic unrest as volcanic activity. Over the next two weeks, sulphur dioxide emission increased tenfold, indicating that magma was rising. During the month of May, seismic activity remained constant, with sulphur dioxide emissions showing a clearly defined and linear increase.

Roughly 15 000 people lived in small villages on the volcano's flanks. Another 500 000 lived in cities and villages on gently sloping alluvial ground surrounding the volcano. Clark Air Base and Subic Naval Base had populations of 14 000 each.

The team decided to act swiftly to:

- monitor and interpret seismic activity, ground deformation and gas emissions
- translate this understanding into a simple warning scheme to which civil defense leaders could key a simple "ready, set, go" evacuation plan

The volcanic cloud over Mt Pinatubo, 12 June 1991.

- reconstruct from the geologic record a profile of Pinatubo's previous eruptions
- use the eruption history to make a hazard map delineating areas of greater and lesser hazard during a "typical" and "worst case" eruption
- communicate this information far and wide to alert both the public and its leaders to the fact that a large eruption could occur.

On 13 May, Mt Pinatubo's level of activity was assessed as Level 2: "moderate level of seismic activity, other unrest, with positive evidence for involvement of magma". This meant that magmatic intrusion into the volcano could eventually lead to an eruption.

After establishing telemetric seismic monitoring and carrying out geological assessment, the volcanic hazard map for Mt Pinatubo was prepared. Acting on briefings by the team, all responsible military and civil defense groups prepared contingency plans tied loosely to the alert levels. A probability tree showing the likelihood of the various outcomes was prepared and presented to involved parties.

During the geological assay, charcoal was found in an old pyroclastic flow east of the volcano. Samples were sent for radiocarbon dating. The information suggested that

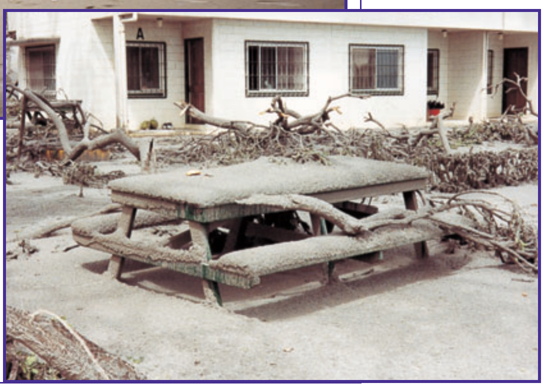
Pinatubo's eruptions recurred every 500–1000 years. As 500 years had passed since the last eruption, this meant an imminent explosion was plausible. Base officials were informed of the chance the base could be swept by pyroclastic flows or hot lahars, either of which would be deadly.

On 5 June the alert was raised to Level 3 and on 7 June further increases in seismic activity, including events suggesting dome growth or shallow intrusion, prompted raising the alert to Level 4, indicating a possible eruption within 24 hours. A dome was confirmed on the morning of 8 June.

This rapid raising of alert levels forced civil and military leaders to accelerate contingency planning. Within days, plans emerged to help officials conduct rapid evacuations and anticipate and prepare for blocked transportation routes, disruption to electrical power and telephone services and other impacts.

On 10 June, 14 500 USAF personnel and their dependents were evacuated from Clark Air Base to Subic Bay Naval Base. The geologists moved their monitoring station 5 km, from the centre to the eastern edge of Clark Air Base. The general evacuation radius was 25–30 km from the volcano.

The likely scenario described by the geologists was that the volcano would erupt, with prevailing winds carrying most of the ash west over the South China Sea. It was assumed that only a small amount of ash would settle on Clark, as another mountain range lay between the volcano and the base. Personnel from Clark had been instructed to take three days' worth of clothing and toiletries with them, as their expected stay would be short, and once the volcano settled down they were to return to Clark, dust off the ash and return to work.



Ash-covered grounds of the US Subic Bay Naval Base after the Mt Pinatubo eruption of 1991. The weight of rain-soaked volcanic ash was enough to collapse the roofs of many homes in Filipino villages nearby.

The first major eruption began around 9 am on 12 June, lasted 35 minutes, and generated a column of ash and steam rising 19 km, with small pyroclastic flows to the north and northwest.

Further eruptions followed on 13 and 14 June, with a cataclysmic eruption on 15 June. The first eruption was clearly seen, but the eruption on 15 June was obscured by a typhoon that had moved in during the previous night. The typhoon changed the prevailing winds, which now blew to the southwest, carrying large amounts of ash towards Subic Bay Naval Base. Clark Air Base suffered heavy ash fall and pyroclastic flows, which destroyed most of the seismometers. Satellite data showed the climactic eruption cloud rose 12 km high into the stratosphere and spread umbrella-like more than 200 km in all directions.

Ash deposits covered a land area of about 4000 km^2 and buried crops. The weight of the rain-saturated ash, assisted by repeated severe earthquakes, caused many roofs to collapse in the communities around the volcano and on the two large US bases. Over 300 people died during the eruption, most crushed beneath collapsing roofs.[16]

ADF resources used in 1994 and 1998

The ADF support to the Papua New Guinea (PNG) government after the eruption of the Rabaul volcanoes in September 1994 was codenamed Operation Carmine. Three volcanoes in the vicinity of Rabaul erupted on 19 September, covering Rabaul in volcanic ash. Electric power was lost, and the drinking water was contaminated. The local airport and harbour were closed. About 30 000 of the city's population of 70 000 were evacuated. ADF support consisted of three C-130 support aircraft airlifting donated food, fuel, water, medical supplies and personnel over a period of about one week. There were two casualties.

ADF support to the PNG government after the tsunami at Aitape in 1998 was much more extensive. An earthquake occurred about 2 km off the coast on 17 July. 15 minutes later a series of three waves 15 m, 10 m, and 7 m high hit the coast west of Aitape over a 35 km front. The ADF deployed elements of 1 Field Hospital, including 1 Parachute Surgical Team, and a RAAF aeromedical evacuation team, who were joined by PNG, New Zealand, Dutch, US, Japanese and non-governmental organisation teams. C-130 support for transport and aeromedical evacuation was supplied. This support, codenamed Operation Shaddock, continued for 10 days. ADF personnel performed 129 surgical operations on injured victims. Final estimates of the toll of the disaster were 2200 dead, 2000 requiring hospital attention, 1000 requiring hospital admission, and about 10 200 displaced people requiring food, water and shelter.

Conclusions

The 1991 eruption of Mt Pinatubo was the world's largest eruption in more than 50 years. Although many lives were lost, thousands of casualties were averted by timely warnings and subsequent evacuation. Such effective warning of a volcanic crisis is a direct consequence of experience acquired in volcano monitoring and volcano hazard assessment. The eruption highlighted the importance of a rapid, energetic response to volcanic unrest and the significance of effective communication of hazard information to public officials. The eruption exemplifies the ways volcanoes can wreak sudden widespread destruction and havoc on the lives of populations who live near them.

However, unlike some other kinds of natural hazards, volcanoes commonly give significant advance warning. With sufficient volcano monitoring and emergency preparation, the loss of life and property can be minimised and sometimes prevented.

The ADF responses to the Rabaul volcanic eruptions and the tsunami at Aitape illustrate the potential for such natural disasters and the range of responses the ADF may be called upon to provide in the future.

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1800-467425 (1800-IMSICK):
a new health service for ADF personnel within Australia

A toll-free after-hours nationwide 1800 telephone health advisory service is now available to all permanent Australian Defence Force members within Australia.

The service, managed by the Joint Health Support Agency, will allow ADF personnel to discuss health concerns with trained health staff over the phone and receive immediate advice about where to go for appropriate investigations and treatment. The advice will focus on the type of health care needed, the urgency of that need, and what to do until face-to-face medical care is provided. The service will also allow the local Area Health Service to issue reference numbers to authorise treatment and track expenditure.

Aims of 1800-IMSICK

1800-IMSICK aims to make ADF health services more accessible, bringing them closer to where people live or are on holiday, and to ensure that members receive appropriate treatment. It will also enable the member's parent unit to properly follow up treatment regimens and to verify accounts. The new service will streamline the authorisation process for ADF members seeking out-of-hours health care, making it a worry-free and simple procedure at what may be a stressful time.

How will 1800-IMSICK operate?

When an ADF member is sick or injured away from the workplace and out of office hours, he or she simply calls 1800-467425. The call will be automatically diverted to the nearest ADF health facility, where it will be answered by duty health personnel.

The duty health personnel will note the member's personal details, unit and relevant clinical details, then decide on a plan that is best for you. This may include:

- taking your contact phone number so that an on-call Medical or Dental Officer can contact you directly, or
- advising you on accessible treatment facilities in your immediate area (you may have a suggestion of your own based on your local knowledge), and
- issuing a referral number (if required) that will be used to authorise treatment and track expenditure.

Often advice and reassurance is all that is needed. If a member needs to attend a local civilian health provider or a military health provider, the duty personnel will ask the patient to call 1800-IMSICK on the completion of treatment to advise them of the outcome of treatment.