KRAKATOA ERUPTION, 1883

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27 August 2008 marks the 125th anniversary of one of the most significant volcanic eruptions of modern times – that of Krakatoa, known locally as 'Krakatau'. The events of 27 August were the climax of an eruption that occurred over a number of preceding months.

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The island of Krakatau lay in the Sunda Strait, approximately 40km south of Sumatra and 40km northwest of Java.

During May 1883 the island first showed signs that the eruption had begun, with a column of ash from the Perboewatan cone that reached up to 11km into the atmosphere. During June and July, multiple eruption columns were observed on the island at the Danan and Rakata cones. Ash from these columns was reported to have fallen up to 500km away from the island, so were themselves significant events.

By 11 August, the island was covered in volcanic deposits (basaltic, pumice) from explosive activity which had now produced three eruption columns. The climax of the eruption began with further intensification of activity and violent explosions on the 26 August.

Atmospheric pressure waves from the explosions caused structural damage near the volcano and were recorded around the world. Large pieces of volcanic rock ('bombs') were ejected by the major explosions to distances of 40km and ash was deposited to distances of 1850km.

The majority of material ejected during the eruption was displaced in the form of super-heated debris flows ('pyroclastic flows'). These flows travelled across water to around 40km northeast of the volcano and remained hot enough to cause 1000 deaths at Ketimbang on the island of Sumatra.

The explosions that occurred during the eruption climax were audible to a distance of 4,811km (near Mauritius in the Indian Ocean) and were loud enough to wake people 3224km away in South Australia. Deaths related to the eruption are estimated to have been over 36,000 – around 32,000 of these were due to a devastating tsunami triggered by the collapse of Krakatoa.

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The collapse of the volcanic cone caused the largest of several tsunami during this eruption. The largest tsunami waves were reported to be up to 35m when they reached the coast of Java within minutes of the collapse. The waves in this event were recorded on the north west corner of Java at Merak (35m), Telukbetung, Sumatra (22m), Tyringen, Java (22m), Anjer, Java (10m) – all from National Oceanic and Atmospheric Administration (NOAA) Tsunami Database.

The atmospheric effects of the eruption were observed around the globe, seen as halos around the sun and as red skies and spectacular sunsets. This was caused by fine particles of dust and aerosols such as sulphur dioxide being transported around the world within two weeks of the eruption. Almost two thirds of the world was affected and the intensity of the sun's energy reaching the ground in Europe dropped by 20%, remaining 10% below average for several months. Over the northern hemisphere in the year following the eruption of Krakatoa, an average surface cooling of 0.34°C was observed. Although this may have short term impacts on crop growth, its impact is limited, relative to natural climate signals.

Following the eruption, the volcanic cone collapsed into the sea, leaving behind only the southern part of the island, the Rakata cone. Over the last 75 years a younger volcano, Anak Krakatau, has grown and emerged in the place of the previous volcanic cone.

Impact of same eruption today

The accounts of survivors in southern Sumatra confirm that pyroclastic flows travelled across the Sunda Strait. Whether a flow would affect the local population is entirely dependent on its direction of travel from the volcano. In 1883 the flows were directed at Ketimbang, Sumatra. If they were to occur in a future eruption, the islands of Sumatra and Java are well within the possible runout distances of pyroclastic flows. They could cause many thousands of deaths if they were to travel in a northeast or southeast direction again.

The tsunami resulting from volcanic cone collapse destroyed 165 villages around the coastlines of Java and Sumatra, killing 32,000 people. The locations of Ketimbang, Anjer and Tyringen were the worst affected, with over 27,000 deaths in these three locations alone. The closest three provinces to Anak Krakatau now have a combined population of 60 million.

Some of the towns that were subjected to the largest waves on 27 August 1883 are now home to some major industries in Java. Merak is a port servicing Indonesia's largest petrochemical production area, with more than 40 plants in operation near the port. In a repeat of the 35m tsunami wave that hit in 1883, these facilities would be destroyed along with any infrastructure in place.

The town of Telukbetung (now Bandar Lampung) has a population of around 800,000 and is an important port and transport hub for southern Sumatra. Having been hit by a 22m high tsunami in 1883, this port is shown to be at one of the worst locations should a tsunami occur – the port is located at the head of a long narrowing bay, a feature which would funnel a tsunami and amplify its wave height significantly.

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Jakarta (then 'Batavia') was subjected to a tsunami wave of 2.4m height, which is large enough to strip beaches and overtop defences. Coastal infrastructure would be damaged and could lead to a significant number of deaths. Jakarta's position on the leeward side of Java with respect to Krakatau shows that even this does not protect against tsunami run-up, as the waves refract around the island. We could expect to see waves of this height around much of the coastlines of Java and Sumatra, although the topography of both the land and seabed would have great influence on the local impact.

Commercial aircraft would be affected by the ash columns that could be expected to rise from a similar eruption and would cause airlines to ground their fleets and require diversion for many hundreds of kilometres around the volcano. The area affected would be highly dependent on wind speeds and direction around the source of the column.

Heavy ash fall in the tens of kilometres around the volcano poses a real danger of building collapse, and the fatalities and economic loss that comes with it. It is estimated that 25cm of ash can collapse most roofs; again, the area affected would be dependant on wind speed and direction.

Modeling of volcanoes

Due to the cost and logistics of volcano monitoring, a limited number of key volcanoes throughout the world are subject to continuous monitoring programmes. Techniques include radar/satellite imagery and visual observations to monitor deformation of the flanks and cone of a volcano, seismic networks, thermal and geochemical monitoring. These methods use activity at the surface to provide indications of how magma is moving within the volcano and are known as eruptive pre-cursors. The observation of increased deformation rates, seismicity and gas mission can all indicate increased volcanic activity and highlight the potential for an eruption in the future.

In limited circumstances, where a volcano has been consistently well-monitored, certain cycles of pre-cursors can be identified and used to predict eruptive activity. However, it is still not possible to provide these sorts of predictions for the majority of volcanoes. In many cases, increased pre-cursor activity has continued for several months before eruption and in other cases the activity has ceased without any eruption.

Modelling of ash cloud dispersal is possible and has been used following eruptions in New Zealand to forecast the extent of ash fall, given the regional atmospheric conditions and erupted volume of debris.

Most hazardous volcanoes today

The wide range of volcanic hazards puts over 500 million people around the world at risk from volcanoes, in cities on every continent. The continuing growth in urban population, particularly in developing countries, only increases the population at risk.

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Effusive volcanoes such as Kilauea in Hawaii pose hazards in terms of lava flow destroying land and property; however, the most hazardous volcanoes are those capable of explosive activity and that have large populations in the vicinity. The Nevado del Ruiz eruption in Columbia in 1985 highlights the greater dangers of volcanic mudflows (lahars); 23,000 people died when lahars traveled over 100km from the eruption site and destroyed the town of Armero burying people and buildings in mudflows up to 5m deep. It is recognised that an eruption of Mount Rainier in Washington, US, presents a great hazard of lahars which could threaten the highly populated areas around Tacoma and Seattle.

In Europe, Vesuvius and Campi Flegrei pose hazards to the city of Naples. A 'modest eruption' at Campi Flegrei would put 2–400,000 people in danger, while an eruption of Vesuvius similar to that which occurred in 1631 would require 700,000 to be evacuated. These estimates are derived from mapping previous tephra fall and pyroclastic deposits, which is a common method for construction of hazard maps and evacuation plans.

Insurance cover for losses arising volcanic eruptions is available in the US and in the 1990s Hawaii set up an insurance pool protecting homes against lava flow in the state. State Farm advises that most homeowner policies cover volcanic eruptions as standard, including loss from lava flow, dust, ash, fire and explosion. However, longer term loss from ash and dust, or removal of ash debris is not covered. In other countries, cover against volcanic eruptions is provided as standard in with deductibles varying according by risk zone for some lines of business. In other cases, this is provided as extra cover. A common feature of volcanic cover is the 'hours clause', which limits a single event to a 72 hour period.

Although many of the world's most hazardous volcanoes occur in developing countries where insurance penetration is less than developed countries, more attention should be paid to volcanic hazards – losses from which have previously reached $1bn in a single event (Mount St Helens, 1983) and $95m (Soufrière hills, Montserrat, ongoing since 1995).

Prevention of disaster

Slow moving lava flows have been successfully diverted in the recent past to prevent destruction of property on Mount Etna and these methods can be adapted to other locations. In 1983, attempts to control lava flows were perceived as a success, when earth barriers and concrete blocks were used to slow the lava, and flows were diverted by blasting holes in lava tubes. In this event the flows were prevented from reaching the town of Zafferana, although there is some debate as to whether they would have stopped short of the town even without intervention. An unfortunate consequence of the perceived success was subsequent complacency that this could be achieved in the case of every eruption. This is not the case – the lava flow must be slow-moving and begin a sufficient distance from the populated area for diversion attempts to be successful.

There is little available protection from the devastating force of a pyroclastic flow (even across tens of kilmetres of water, as shown in 1883) and ash cannot be stopped from falling. Volcanic mudflows are also extremely difficult to protect against although we have the benefit of knowing the likely channels that these lahars would be confined to. As such, monitoring and early warning systems remain the most effective method of saving lives.

Tsunami following volcanic eruptions are also best mitigated through use of early warning systems, such as that put in place following 2004 Indian Ocean

Education on the warning signs of eruption and monitoring the volcano for unusual/ accelerated activity remain the most effective ways to mitigate losses in volcanic disasters

tsunami, and by education on warnings and evacuation plans. In addition, areas of mangrove vegetation have been shown to successfully mitigate the energy of tsunami and can protect coastal communities from destruction in waves of several metres in height.

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In the majority of explosive volcanic eruptions, destruction of property and agricultural land cannot be prevented due to the devastating force of volcanic hazards – we can only rely on natural topography to direct lahars, and wind direction to direct ash fall away from major population centres. The impact of volcanic disasters on loss of life can be mitigated and is best achieved through education of the local population on naturally occurring warning signs, implementation of early warning systems and evacuation plans

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