Chapter 4

PROTECTIVE MEASURES

The purpose of this chapter is to describe the measures which can be taken to provide temporary or permanent protection against the various destructive phenomena which accompany volcanic eruptions.

4.1 Protection against ash falls

The main effects of heavy ash falls are:

(*a*) Complete blackout;

(*b*) Burial of low structures;

(*c*) Overloading of roofs; and

(*d*) Blanketing of vegetation and crops.

The heavy ash falls downwind of large eruptions can cause sudden complete darkness and reduce visibility to such an extent that even powerful lights can be seen only metres away (figure 12).

Vital equipment such as fire hydrants is sometimes buried under deep ash in heavy falls, so that they are difficult to find when urgently needed to deal with fires caused accidentally or by the fall of hot material from the volcano. This problem can be overcome by keeping lengths of fire hose permanently connected to the hydrants and under pressure, and by keeping them clear of the ground. During the Heimaey eruption of 1973 this was practised successfully, and the fire services were able to continue in full operation in the town of Vestmannaeyjar even when the hydrants were buried under thick layers of ash.

The main cause of damage by heavy ash falls is the accumulation of ash on the roofs of buildings, which collapse under the additional load, especially if the ash is wet. In areas where heavy ash falls are liable to occur, an ash removal plan should be prepared and equipment kept ready for this purpose. A survey should be made of the strength of roofs in the area and of the maximum thickness of ash that they will bear without danger of collapse, bearing in mind that whereas the bulk density of dry volcanic ash ranges from 0.5 to 0.7 ton/m^3, that of wet ash may reach 1.0 ton/m^3.

During the heavy ash falls on the town of Vestmannaeyjar in the island of Heimaey in 1973, houses whose roofs sloped at angles greater than 20° to the horizontal suffered no damage from ash, whereas roofs which were flat or only slightly sloping collapsed under the weight of ash if this was not repeatedly cleared off. Steeply-sloping roofs covered by metal sheeting do not retain the ash and are also safe from ignition by hot lava fragments (figure 13). In areas where ash falls are a major hazard, the observance of appropriate building codes and construction practices can therefore reduce significantly the risk of damage.

Ash falls can have some important indirect effects. The ash may contain volatile components, such as fluorine, which are highly toxic. Another threat comes from the powerful electric fields generated in ash clouds, with consequent intense and frequent lightning discharges (figure 14) which interfere with radio communication and sometimes damage electrical installations or start fires in buildings or vegetation. This should be foreseen when planning rescue and relief operations.

When a heavy ash fall occurs, it may be difficult or impossible to provide protection for all individuals in a densely populated area. However, a suitable public information programme can play a large part in helping people to follow the best course of action when an emergency arises. When ash clouds are drifting large distances downwind, an ash fall forecast can be added to the normal weather forecast for the area. This was done during the 1980 eruption of Mt. St. Helens in the USA. Radio broadcasts can give information on the shortest routes out of an ash fall area (e.g. by taking a direction across the wind), and on how to avoid breathing ash and fine dust by using moistened cloth filters over mouth and nose. People can also be informed about the danger of accumulation of ash on house roofs and on how to clear it off.

Rescue and relief personnel on duty in areas where there is a heavy ash fall can be protected by helmets with face screens and by padded, heat-resistant capes for the neck and shoulders. Gas masks are required if toxic gases are detected.

Various measures can be taken to protect property against ash falls: shovelling or sweeping by hand is the most common way of removing ash from roofs (figures 15 and 16). On Heimaey, this was done using a large scraper consisting of a metal plate 1.5 m by 1.0 m, fastened on wooden runners controlled by means of ropes running down to the street.

On large buildings with flat roofs of high bearing capacity, small mechanical shovels can be used to remove the ash from the roof, provided that the shovel can be hoisted on to the roof by crane or landed by helicopter. This method was used to clear some 600 tons of ash from the roof of the Municipal Hospital of Vestmannaeyjar in 1973.

When large quantities of ash are shovelled off a roof, it accumulates at the sides of the building and can exert pressure on the walls (figure 13). Bulldozers are needed to clear these ash heaps and to keep the streets clear, or at least level. Finally, in heavy falls, it must be remembered that power lines may present a hazard to people in poor visibility, particularly when their height above "ground" has been reduced by the thickness of the ash fall.

On the positive side, the ash cleared off roofs and streets makes excellent foundation material for roads, airport runways and building sites. On Heimaey, the ash cleared from the town of Vestmannaeyjar was used to extend the runway at the island's airport and to level out an old lava flow for a settlement to replace the houses destroyed during the eruption.

In the immediate vicinity of an eruption, the fall of red-hot ash can start fires, and if the fragments are large enough they can smash windows and set fire to curtains and furniture inside houses. During the Heimaey eruption, 25 houses were burnt down because of this, but further fire damage was prevented by protecting roofs and windows facing the volcano with metal sheeting. Fuel tanks were protected by fitting fine wire mesh over the ventilation tubes.

4.2 Protection against volcanic blasts and pyroclastic flows

In areas subjected to the most violent types of eruption such as pyroclastic flows and horizontally directed blasts, the destruction of normal buildings will be nearly total. The only structure capable of giving protection against such eruptions is an underground shelter with reinforced walls and ceiling, and hermetically sealable, impact-resisting doors and windows, such as those intended to serve as nuclear bomb shelters in some countries. However, in most countries with high volcanic hazards, the cost of building such shelters is beyond the means of private home-owners or even of the state.

It would, however, be appropriate and justifiable to construct blast-resistant shelters at volcano observatories and for police and other officials who maintain essential services in areas which have been evacuated. Costly and important installations, like power plants and communication centres, or important archives which have to be located in high-risk areas would merit similar protection. With the gradual increase of reinforced concrete construction in the developing countries, it may also be possible to design simple modifications to doors, windows and ventilators of basements or underground garages to make them instantly convertible into volcanic eruption shelters in emergencies.

A lower but often adequate level of protection could be provided simply by arranging for large public buildings (and especially future construction of this kind) to have doors and window shutters which can be sealed completely against the hot dust clouds which spread from the fringes of pyroclastic flows, and which in numerous eruptions have infiltrated into houses and asphyxiated the occupants even though the houses have remained intact.

4.3 Protection against mudflows

Small mudflows can be diverted by barriers or by artificial channels which lead them away from valuable land or property, but in most cases the volume and force of the mud is such that it is beyond human power to control (figure 6).

As a general principle, it is unwise to build any permanent settlement in an area which is known to have been affected by mudflow in the recent past. The identification of such areas is described in the companion handbook to the present publication (Crandell *et al.*, 1984). However, ignorance of this principle has resulted in many settlements on or near volcanoes being exposed to this particular hazard. In these cases, the only possible protection is flight from the area in good time, when an eruption is threatening or has started and mudflows are likely.

Whenever a volcano is erupting and is seen to be depositing large amounts of ash on its upper slopes, all permanent settlements in the valleys around the volcano should be evacuated as a precautionary measure, especially from those valleys where mudflows are known to have occurred in the past. People may be allowed to return into the danger areas to work, but on condition that an effective warning system is established so that they leave the area immediately a mudflow is detected or expected.

Such warning systems have to be carefully designed and operated, since mudflows can travel at very high speeds (up to 100 km/h) and people in their paths have only a few minutes in which to escape to higher ground.

4.4 Protection against lava flows

The first known attempt to divert a lava flow was made in Sicily in 1669, when a large flow from Etna was advancing towards the city of Catania. Several dozen men from the city covered themselves with wet cowhides as a protection against the heat, and with iron bars managed to open a breach in the side of the flow, through which the lava flowed out in another direction. Unfortunately this new flow threatened the village of Paterno, whose inhabitants sallied forth in large numbers to put a stop to the operation. The men of Catania were forced to abandon their efforts, the breach soon clogged up and the main flow continued on into the city.

Since 1669, several other methods of diverting lava flows have been tried:

(a) *Bombing*

Low-viscosity basaltic lava flows have been bombarded from aircraft in attempts to open new channels or to break up and clog flows which were threatening valuable property. For instance, during the 1942 eruption of Mauna Loa in Hawaii, a lava flow was breached high on the slopes of the volcano and the lava front 20 km away ceased its advance soon after; however, the intensity of the eruption had decreased in the meantime, so that it could not be proved that it was the bombing that stopped the advance of the lava.

Bombing from aircraft can only be attempted in good weather and with good visibility; during eruptions, however, visibility is often very poor, and violent air turbulence can also make the operation dangerous. Air-to-ground guided missiles might possibly give better results but they have not yet been used for this purpose.

Even under the best conditions, bombing from the air is generally not accurate enough, and there is always the risk that a misdirected bomb may increase the flow in the wrong direction. It is doubtful whether bombing could have any significant effect on thick flows. An alternative method, the explosive breaching of lava flows, using charges installed by hand into shallow boreholes, was experimental on Etna in May 1983.

(b) *Diversion barriers*

There has been much discussion of the feasibility of constructing barriers to divert lava flows. In 1881, W. R. Lawrence proposed to build a barrier to slow down a flow from Mauna Loa which was threatening the city of Hilo, but the eruption ceased before the work was completed.

It has been observed on several occasions that lava tends to flow around obstacles such as houses and stone walls rather than crush them. During the eruption of Vesuvius in 1906, lava flowed through the streets of Bosco Trecase without destroying the buildings. However, more viscous lava, such as that produced by the 1983 eruption of Etna, pushed down masonry houses (figure 10).

In the Krafla area in northern Iceland, where the lava is very free-flowing, two barriers have been built, one to protect a village of 200 inhabitants and the other a diatomite factory. A small ridge in the terrain has been levelled by bulldozer to direct the lava away from the settlements. There has been no eruption since this work was completed, so it is not yet known how effective it will prove to be.

On Etna in 1983, barriers were built at considerable expense using a fleet of bulldozers and trucks, and these were notably successful in diverting a lava flow from a hotel and recreation area.

(c) *Cooling by water spray*

The idea of cooling lava fronts by spraying large quantities of water on them has been discussed for some time and was tried out on a small scale in 1960, when the Hawaii Fire Department sprayed water from two fire hoses on to a lava front and is believed to have succeeded in slowing it down for a while.

The first large-scale attempt to slow down a lava flow by water-spraying was made on Heimaey, Iceland, in 1973. The lava was approaching the town of Vestmannaeyjar and its harbour, vital to the existence of the people on the island.

About two weeks after the beginning of the eruption, when the lava front was approaching the harbour entrance, pumps were collected from the Civil Defence, the Fire Department and other organizations, and about 100 litres of water per second were sprayed on to the lava front over a width of about 500 metres. Soon after the pumping had started it was noticed that the lava front piled up where it was being sprayed, to a height of about 20 metres and that it had slowed down, while on either side of the cooled area it continued its advance at the same speed as before. It was therefore decided to increase the pumping capacity, and a special pumping ship was sent to the island, to pump sea water from the harbour on to the lava front. The pumping capacity was thus increased to 400 litres/second, and subsequently to 1,200 litres/second. It is estimated that, in the 150 days during which this operation continued, 6.2 million cubic metres of sea water were sprayed on to the lava.

After the end of the eruption, boreholes were drilled into the lava to measure the effect of the water spraying. In places where there had been no spraying, a temperature of 500-700 °C was reached at a depth of 5-8 metres below the lava surface, but in the sprayed area the same temperatures were not reached until a depth of 12-16 metres.

It has been debated whether the operation was worth while. The total cost of the spraying has been estimated at 1.6 million dollars. Since every metre that the lava front advanced meant some destruction of property in the town, any slowing down of the movement meant value saved. It is impossible to say how many metres more the lava would have advanced without the cooling but it is certain that if the cooling saved the port installations, it paid for itself many times over.