CHAPTER II

VOLCANIC ACTION AND VOLCANIC PRODUCTS

Volcanic activity ranges from gentle outpouring of lava to violent explosions that throw great volumes of rock fragments high into the atmosphere. The nature of the activity depends largely on two factors: the viscosity of the magma, or hot rock, reaching the surface, and the amount of gas involved. The gas may originate within the magma, or it may be the result of the magma coming in contact with ground water or surface water, generating steam. Phreatic eruptions, produced by rapid heating of ground water, may throw out only fragments of old rocks.

Magmatic gas escapes readily from highly fluid lava, with little or no explosion. In viscous lava, however, bubbles of gas separating from the melt can escape only with difficulty; consequently they tend to accumulate in the melt until the increasing pressure is great enough to burst the confining liquid and solidified rock, producing an explosion. The strength of the explosion depends on the amount of gas and the pressure attained. The material thrown out by the explosion may consist of a spray of liquid blobs, which tend to be further torn apart by expansion of the gas within them; or it may consist of solid fragments of older rocks, or of solid or semi-solid fragments of lava of the current eruption. Commonly, both types of material are present. The liquid bits chill in the air to form glass.

The viscosity of erupting magma is partly controlled by such factors as temperature and the amount of solid load, including both fragments of extraneous origin and crystals formed within the magma itself; but the most important factor is the amount of silica in the melt. The viscosity appears to be related more to the degree of silica saturation than to the absolute amount of silica present. Thus, lavas in which the silica is largely or entirely bonded to various bases are less viscous than those in which silica exists in excess of the amount in the silicate compounds, probably because of the formation in the latter of extended polymers of silica tetrahedra. Because excess silica is more apt to be present in the melts richest in silica, viscosity tends to increase with silica content: dacites and rhyolites tend to be more viscous than andesites, and andesites more viscous than basalts. But trachytes with higher silica content than dacites may nevertheless be less viscous, owing to the lesser amount of silica in proportion to the bases, especially the alkalies.

Because long periods of inactivity allow differentiation in the magma chamber to produce eruptible magma of higher silica content, and also of greater volatile content, eruptions following long quiet periods are apt to be violently explosive.

Extraneous water may transform an eruption that otherwise would have been gently effusive into one that is moderately, or even violently, explosive. The eruption of Surtsey Volcano, in the ocean south of Iceland, provided a clear illustration of this (Thorarinsson, 1967). In the early stages, when ocean water had easy access to the erupting vent, the activity was explosive, throwing showers of debris 200 to 300 meters into the air. But eventually the cone of debris growing around the vent formed a barrier between the ocean and the erupting lava, and the eruption became a gentle fountaining and outpouring of fluid lava.

The usual classification of eruptions is based on the character of the activity. Table 1 summarizes the classification and the nature of the products of each eruption type.

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Hawaiian-type eruptions are usually basaltic, less commonly nephelinitic or andesitic, and rarely of other compositions. The lava flows are nearly always pahoehoe or aa, only very rarely block lava. Repeated eruptions build shield volcanoes. Strombolian-type eruptions characteristically produce andesite or basaltic andesite flows of block lava, but aa flows may form, and magma composition may range from nephelinite to trachyte. Repeated eruptions build composite volcanoes ("stratovolcanoes"). Vulcanian-type eruptions most typically are dacitic to andesitic, less commonly rhyolitic or basaltic, and the lavas are usually short thick block-lava flows, but flows may be entirely absent. Peléean and Plinian eruptions may be regarded as special types of Vulcanian activity, and usually are only occasional or single events in the history of a major composite volcano. Most commonly they involve magma of dacitic, trachytic, phonolitic, or rhyolitic composition, but Peléean eruptions of basaltic magma are known (Taylor, 1963). Except for the rhyolitic ash flows, flood eruptions are usually basaltic, but floods of trachyte and phonolite have been described in central Africa. Repeated flood eruptions build up lava plains or plateaus.

Lava flows

The volume, extent, thickness, and speed of advance of lava flows vary greatly. The extent and thickness depend on the volume, the fluidity of the lava, and whether or not it is free to expand laterally. The flows are closely controlled by the topography of the underlying surface, but deviations from paths following shallow valleys can occur, especially with the more viscous flows.

The most fluid lavas are basalts and related types. Where they are free to spread over moderate slopes, basalt flows usually are less than 5 m thick, and even on slopes less than 3° they commonly are less than 20 m thick. The most voluminous lava flow in historic time was that of the 1783 eruption of the Laki fissure, in Iceland, which exceeded 11.6 km^3. Largely confined to two valleys, the flows reached more than 50 km from the vents (Thorarinsson, 1970). Some prehistoric flows were even greater. The Great Thjorsa flow, in Iceland, has a length of 125 km, an area of 710 km^2 and a volume of about 13 km^3. Its thickness averages about 19 m (Kjartansson, 1967). The Roza flow, in eastern Washington State (USA), is reported by Mackin (1960) to have an area of nearly 52,000 km^2, and a volume of 2,500 km^3! The basaltic lava flows of Hawaiian volcanoes (plate 2) are much smaller, the areas covered during single eruptions ranging up to 90 km^2, and the volumes up to 0.46 km^3 (Macdonald and Abbott, 1974, p. 56, 74). Observed speeds of advance of Hawaiian lava flows have ranged from less than 10 m/hour on a slope of 1°, to 100 m/hour down slopes of about 3° and 9 km/hour down slopes of about 11°.

Fluid basaltic flows are generally of pahoehoe or aa type (Macdonald, 1972, p. 71-89). More viscous lavas tend to form block lava flows (Macdonald, 1972, p. 91-97) which are generally thicker and shorter than those of pahoehoe and aa. Most of them are between 8 and 35 m thick, and some are more than 300 m. Their speed of advance commonly is only a few meters a day. They seldom attain lengths as great as 5 km, but a dacite flow in British Columbia is 17 km long and more than 240 m thick. A trachyte flow on the Island of Hawaii is 10 km long and more than 300 m thick.

Certain characteristics of relatively thin and fluid basaltic lava flows make it possible that their spread can be controlled and their courses directed to some degree. Well established pahoehoe flows are fed by movement of the fluid lava through pipe-like lava tubes. If the tube can be clogged and its roof broken open, it may be possible to cause the liquid lava to spill out high on the flank of the volcano where it will do little or no harm, while the reduction of the supply to the flow front causes it to

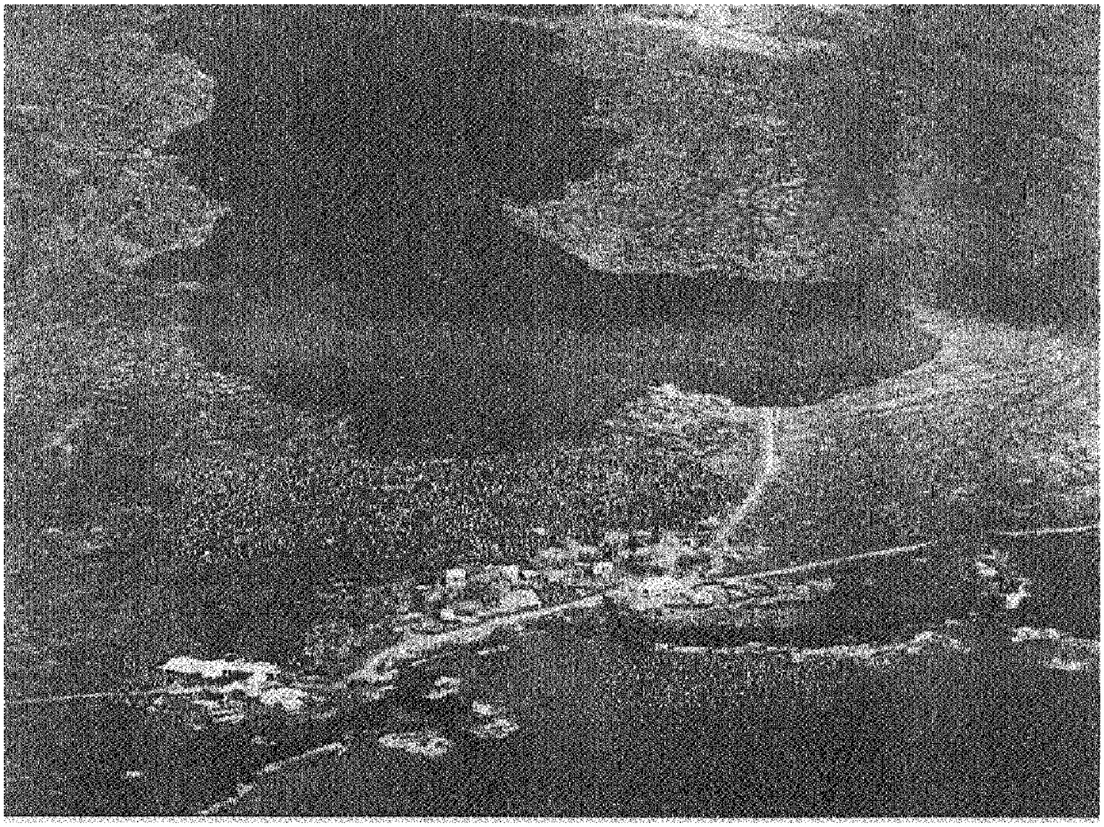

Plate 2. A lava flow approaching Hoopuloa, on the west slope of Mauna Loa Volcano, Hawaii, on April 17, 1926. The village was destroyed the next day.

(Source: U.S. Air Force).

stop advancing toward some area (such as a city) that it is desired to protect (Finch and Macdonald, 1951; Macdonald, 1972, p. 419-421). The most practical means of breaking open the tube roof probably in most cases is by bombardment. Clogging of the tube is partly by debris from the roof, but violent stirring of the liquid in the tube by bursting bombs may result in transforming it into more viscous aa, which moves through the tube less readily, and may even clog it completely. The method was tried on the 1935 lava flow of Mauna Loa, Hawaii, under the direction of T.A. Jaggar. The eruption had been in progress for 5 weeks, and the lava flow was 25 km long and advancing toward the city of Hilo. Bombs weighing about 270 kg were dropped about 3 km below the lower vent of the flow, the feeding tube was broken open, and lava overflowed around the breaks. The rate of advance of the flow front slowed greatly within 36 hours, and ceased altogether five days later.

Aa flows are usually fed through open channels. Repeated overflows build natural levees along the sides of the channel, and after a time the surface of the lava stream in the channel may be a few meters above the surface outside the levees. If the levee is broken down by bombs, or by other means, the liquid of the river will escape laterally, reducing the amount moving down the channel to feed the flow front, and the advance of the front will slow or stop. The method was tried on the 1942 flow of Mauna Loa, under the direction of R.H. Finch. Despite the fact that poor visibility prevented the use of the most promising targets, the bombing broke down the levees and caused the fluid lava to flood out of the channel. The advance of the flow front, 20 km down slope from the bombing site, stopped within about a day.

The upper slopes of Mauna Loa are wholly uneroded, and the adjacent land surface is lower than the flow; but where lava flows are contained in valleys that are deeper than the flow is thick it may not be possible to cause local escape of the fluid lava by bombing. It is still possible, however, that bombing might sufficiently increase the viscosity of the lava in the tube or river to cause the flow to thicken in the upper valley, and the advance of its front to slow or stop.

A third bombing method involves the breaking down of the wall of the cone at the vent. Commonly, the pool of lava in the cone stands a few meters above the surrounding land surface, and shattering of the cone wall will allow it to escape laterally, robbing part or all of the supply of fluid lava from the flow. The method has not actually been tried, but a natural collapse of the cone wall during the 1942 eruption of Mauna Loa (a few days before the bombing) diverted lava from the flow and caused the advance of the flow front to slow temporarily. The walls of the cones are commonly thin enough to make their breaking down by bombs feasible.

Success in diverting lava flows by bombing depends on several factors. Bombing may be ineffective until the flow has developed a well-established feeding tube, a channel confined between levees at a level above its surroundings, or a lava pool confined at a high level in a thin-walled cone. Even when one or more of these conditions exists, there must also be good visibility to permit selection of the best targets and accurate bombing. Very commonly, during eruptions visibility from the air is poor because of volcanic fume, smoke from burning vegetation, and ordinary clouds. Even if bombing can be accomplished, the successful diversion of the flow is dependent on favourable topography. If a flow is in a valley appreciably deeper than the flow is thick, there is no hope of directing the diverted lava out of the valley. The new lava stream will simply follow the margin of the old one, and may actually flood over the old one and rejoin its feeding river down slope. Precisely this happened during the 1942 eruption, but even the temporary diversion was enough to allow the lower end of the flow, deprived of most of its supply of new lava, to cool and increase in viscosity sufficiently for it to stop advancing. In other flows the advance might not stop entirely, and might start again when the diverted lava returned to the feeding channel. However, even a mere delay in the advance of the flow front may be of great value. Under such circumstances we are fighting a battle against time. Most eruptions are short, and if the advance of the flow can be slowed, the eruption may end before the flow reaches the area we are trying to protect.

Although there does appear to be a considerable possibility of diverting fluid basaltic lava flows by bombing where conditions are favourable, it is not at all certain that the method would work on the more viscous block lava flows. Experimentation on this, where it can be done without risk to lives or property, is indicated. Fortunately it is the more fluid flows that spread to the greatest distances, and are most likely to damage important areas.

Diversion of lava flows from important areas may also be accomplished by means of artificial walls, designed not to act as dams, but to turn the flow through a relatively small angle into a new course. The possibility depends on the fact that many flows exert a surprisingly small amount of thrust against objects in their path (plate 3). Numerous examples could be cited of both pahoehoe and aa flows piling up behind loose stone walls, and eventually spilling over them without pushing them over. Even the more viscous block-lava flows sometimes thrust very little. The masonry church at San Juan Parangaricutiro, Mexico, was surrounded and buried to the roof by a flow from Paricutín Volcano, but the walls were not crushed and the interior of the building remained open except for small amounts of lava that dribbled in through windows and doors. On the other hand, the 1928 lava flow of Etna exerted enough thrust to push over rather weak masonry walls in the village of Mascali.

The diversion barriers can be constructed by bulldozers, using loose rock materials readily at hand, or ripped up from the substrata by the bulldozers. The height of wall that is necessary depends on the local topography, and the size of the lava flow it is hoped to divert. Observations show that aa flows will pile up to a height of a few meters above such a diverting ridge without spilling over it to any important extent. Thus, during the 1955 eruption of Kilauea, Hawaii, a railroad embankment about 3 m high successfully turned an aa flow 5 to 8 m thick, with only negligible spill-over. Wall heights of 6 to 10 m appear adequate to turn most Hawaiian flows. Barriers of this sort (fig.2) have been suggested to divert lava flows of Mauna Loa away from the central part of the city of Hilo and its port (Jaggar, 1945; Macdonald, 1958). Objection has been raised (Wentworth, Powers, and Eaton, 1961) that the channels created by the proposed barriers might not be large enough to carry the flow; but the volumes cited appear to be improbably large, considering the distance of the barriers from any likely vents (Macdonald, 1972, p. 422). More serious seems to be the possibility that an early flow unit might block the channel, so that a later flow unit of the same eruption, reaching the barrier farther up slope, might be caused to overflow the barrier. Such a contingency might be met, however, by hurried construction of a second, parallel barrier farther down slope.

Some experimentation has been done with the construction of diversion barriers, but none has been really properly built. One built during the 1955 eruption was placed at too great an angle to the direction of advance of the flow, but nevertheless it successfully deflected the flow for several hours. Walls built during the 1960 eruption (fig.3) were essentially dams to confine the lava flow within an existing valley, not diversion barriers to turn it to a new course (plate 4). Nevertheless, they did act successfully as diversion barriers for several hours after the lava first came