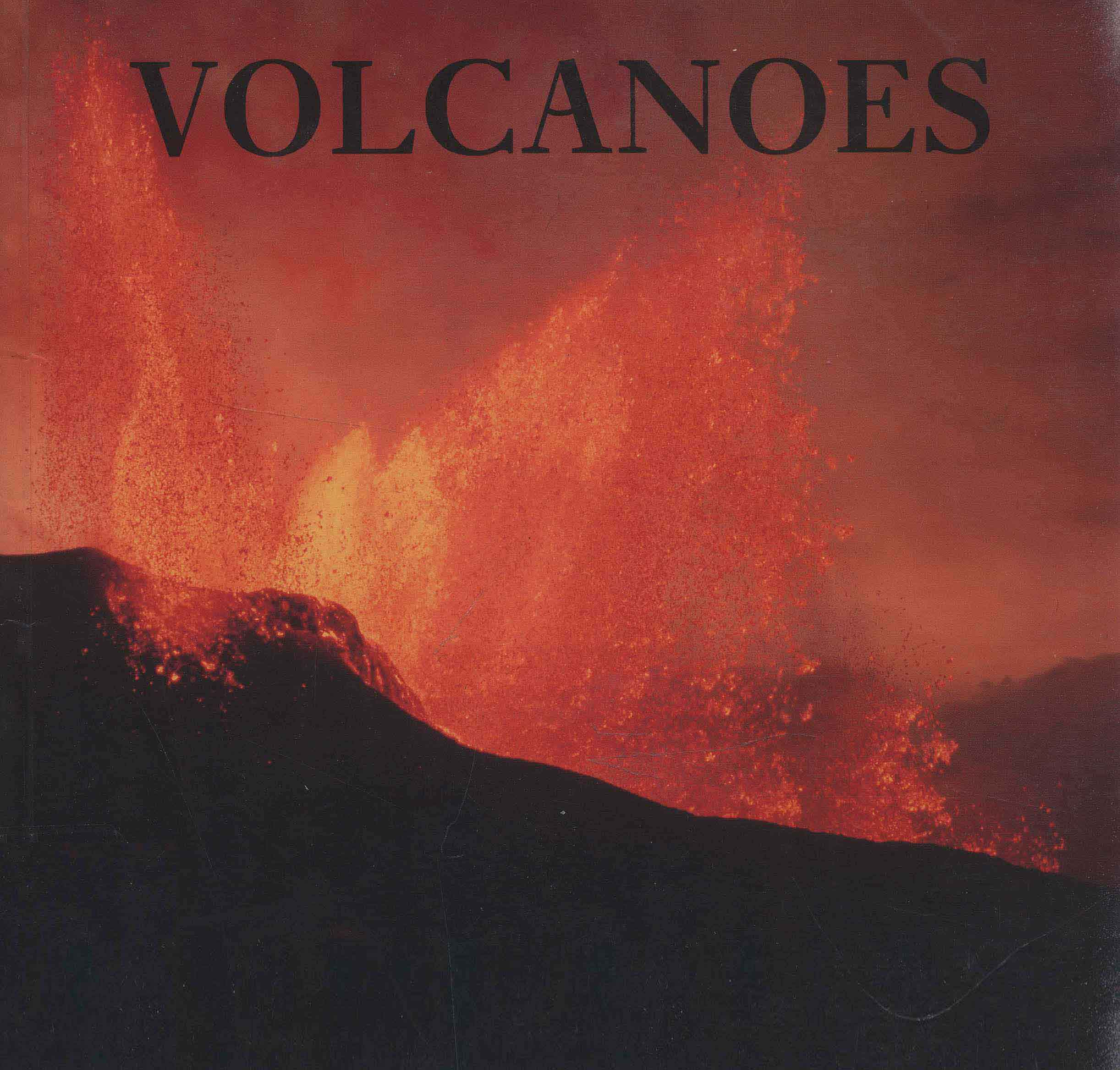
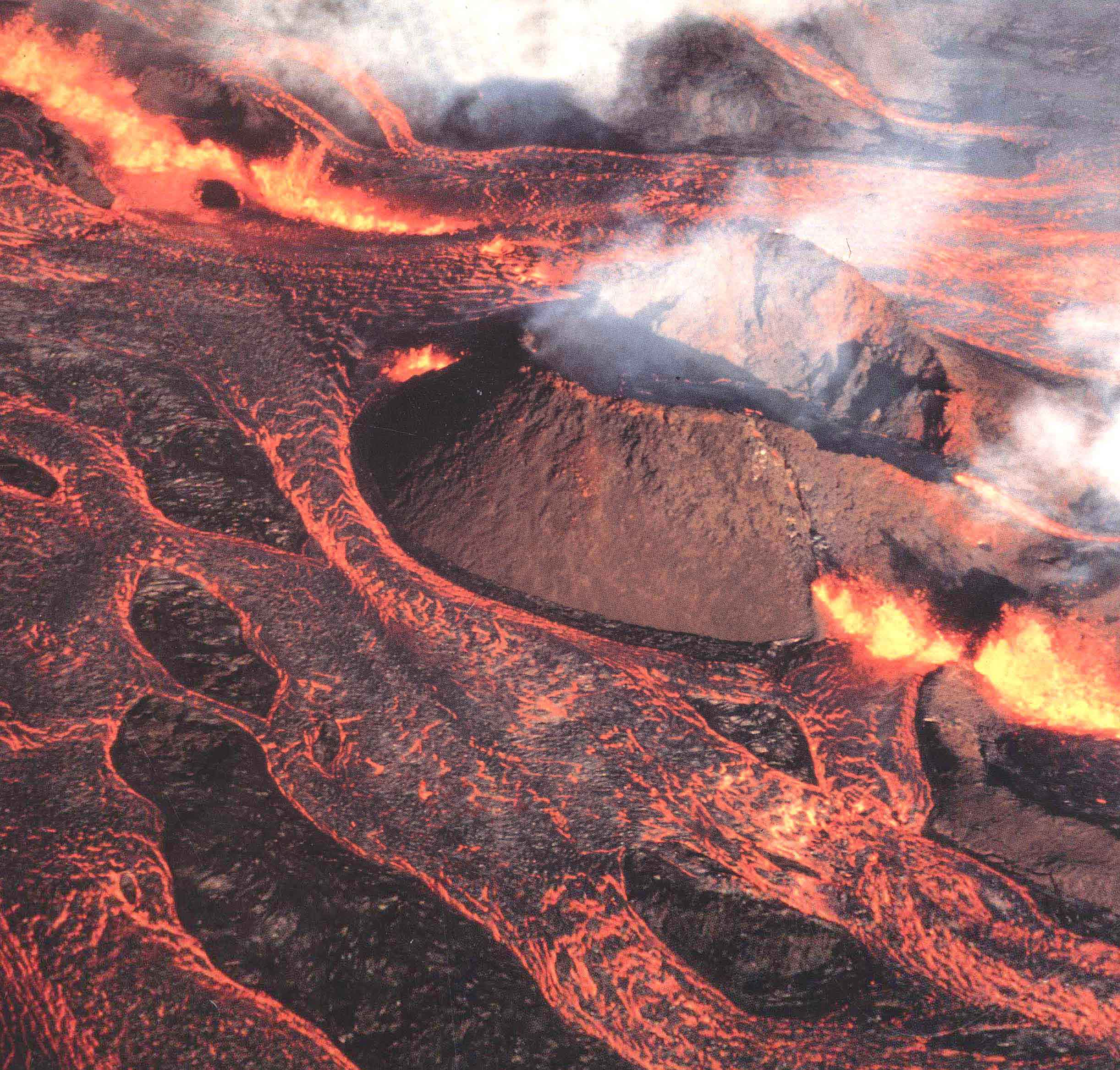
VOLCANOES





CONT

Front cover: fire fountains, Hawaii, 1984. (Left) a Hawaiian cone cut by a fissure eruption: Manua Loa, 1984.

A VOLCANO IS . . .

Magma is the molten material inside or beneath a volcano. During a volcanic eruption, the magma froths, becoming *lava* and volcanic *gas*.

The lava explodes if the gas bursts out, hurling blocks of rock out of the crater. Clouds of fragments billow out or flow away.

Lava oozes from the crater and from cracks in the volcano. The lava flows downhill, following valleys, spreading out as it reaches flat land.

1 Volcano erupting flows of lava.

. . . WHERE MAGMA ERUPTS

Viscosity or 'stickiness' of magma determines the type and frequency of volcanic eruptions. Volcanoes with runny magma – of low viscosity – tend to erupt more often, and with smaller explosions. Volcanoes with sticky, pasty magma erupt infrequently but with enormous explosive energy. Viscous magma is rich in silica.

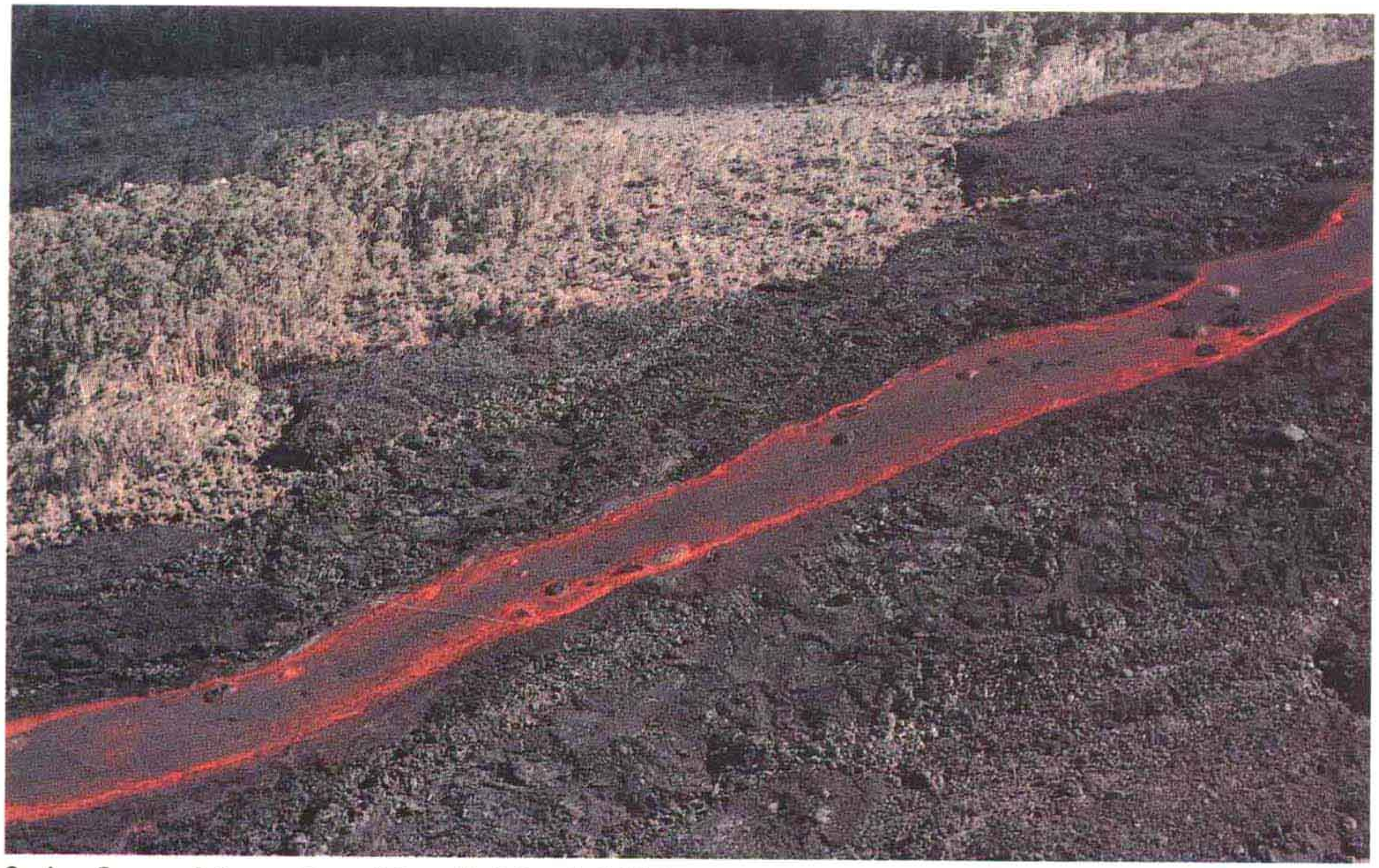
Gas is an important component of magma. When an eruption begins, magma, which has been under high pressure inside the earth's crust, is suddenly reduced to atmospheric pressure and it froths as bubbles of volcanic gas separate out. The gas escapes easily from runny magma, but bursts out explosively from viscous magma. Bubbles make magma more viscous, so the richer in gas, the more viscous the magma. Bubbles of gas rise gently in magma underground. As an eruption begins, it is the topmost, gassy part of the magma which erupts first. When there is no more of the gassy lava foam, the eruption is over for the time being, even though there is still some liquid magma left underground.

Crystals grow in magma as it cools underground. The more crystals within the magma, the more viscous the magma becomes. Some magma is almost wholly crystallized at the time of eruption.

Temperature of magma is very variable. The hottest lava is recorded at 1200 degrees Celsius. The hotter the magma the more easily it flows.

2 Volcano erupting ash.

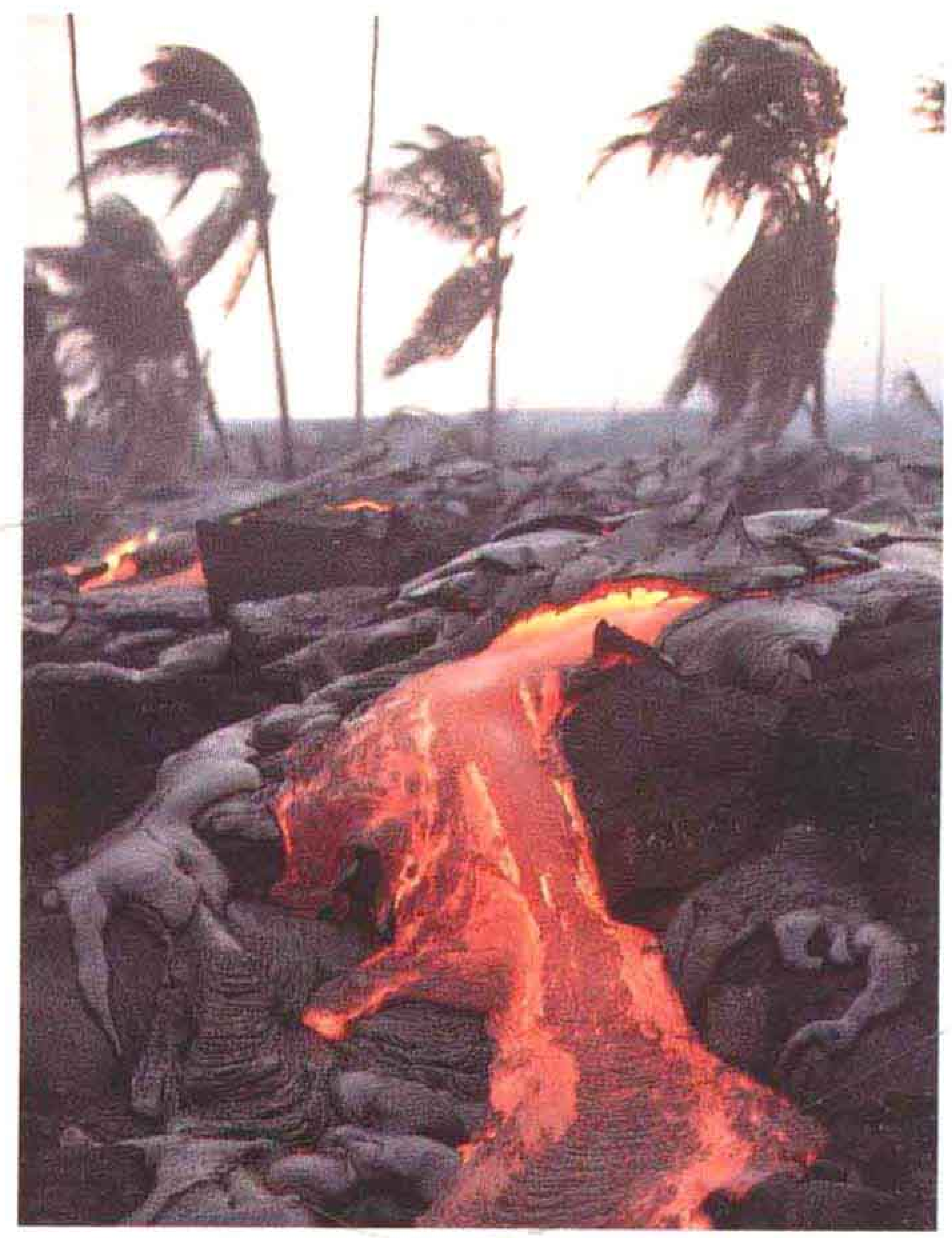
LAVA-FLOWS: RUNNY LAVA



3 Aa-flow at Mauna Loa, Hawaii, March 1984.

Runny lava may flow from a central crater, a small cone on the flanks of a volcano, or from a crack in the ground. Large eruptions of runny lava tend to build gently-sloping volcanoes. The greatest production of lava is on the ocean floor, where runny lava erupts from fissures in the great system of spreading ridges (pp 28, 30). When runny lava cools it forms a hard, dark rock, basalt. This rock is widespread on the continents as well as on the ocean floor. Basalt lava is erupted at temperatures of up to 1200 degrees C. Dissolved gases are released as bubbles; their force may send the lava up as a 'fire fountain'. As lava cools, bubbles may be trapped as cavities or vesicles. In cooled lava these are often filled with minerals, giving a 'spotty' appearance.

4 Front of an aa-flow, Etna, 1983.



5 'Entrail' pahoehoe-flow, Hawaii, 1987.

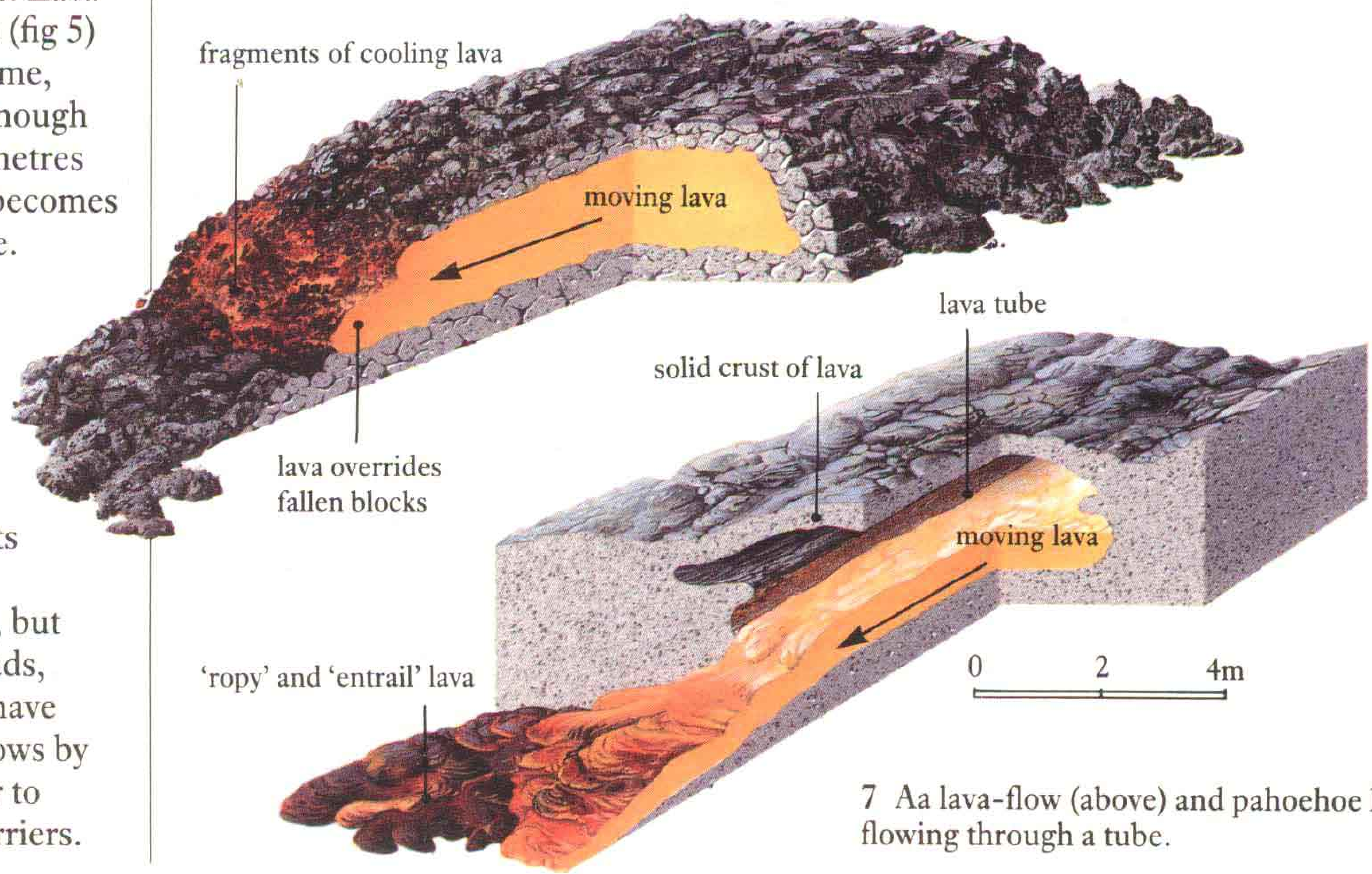
LAVA-FLOWS: RUNNY LAVA

When erupting, runny lava behaves much like a river of water. It will flow downhill, following existing valleys, and may form spectacular falls over cliff edges. Long-lasting eruptions may form lava-flows which travel at up to 50km per hour and reach lengths of a hundred kilometres or more. Because it continues to move rapidly, a flow of this length may only be a few metres thick. Runny lava from a fissure may simply form a vast pool, which slowly cools as a thick sheet. The Deccan Plateau of north-west India (p 33) is made of many such sheets.

As a lava-flow cools it becomes stickier and slower-moving. Lava that solidifies with a rough, clinkery surface is known by a Hawaiian name, 'aa' (figs 3, 4). In a thick flow, the lava cools to form solid basalt, which may crack as it contracts to form regular columns. Lava which develops a continuous skin (fig 5) is known by another Hawaiian name, 'pahoehoe'. Its skin can be cool enough to walk on when only a few centimetres thick. If flow continues, the skin becomes wrinkled, resembling coils of rope. In time a thick crust forms; a central tube of flowing lava (figs 6, 7) may empty to form a long cave once the eruption is over. Lava that erupts under-water is rapidly chilled and may break up into tiny glassy fragments or 'pillows'.

Lava-flows rarely cause death, but may destroy agricultural land, roads, bridges and buildings. Attempts have been made to slow threatening flows by cooling them with water hoses, or to divert them with explosives or barriers.

6 Pahoehoe tube, Hawaii.



7 Aa lava-flow (above) and pahoehoe lava flowing through a tube.

LAVA-FLOWS: PASTY LAVA

Lava containing large amounts of silica is very viscous, or pasty. Although runny lava is erupted from volcanoes worldwide, pasty lava is more restricted, mainly to continental edges and strings of islands such as the Caribbean and Japan. Depending on its composition, pasty lava cools to form rocks such as andesite, trachyte, dacite, obsidian and rhyolite. Most pasty lava is erupted explosively, though if the gas content is low, it issues like stiff toffee. Large-volume eruptions can produce very thick lava-flows which move exceedingly slowly (fig 11).

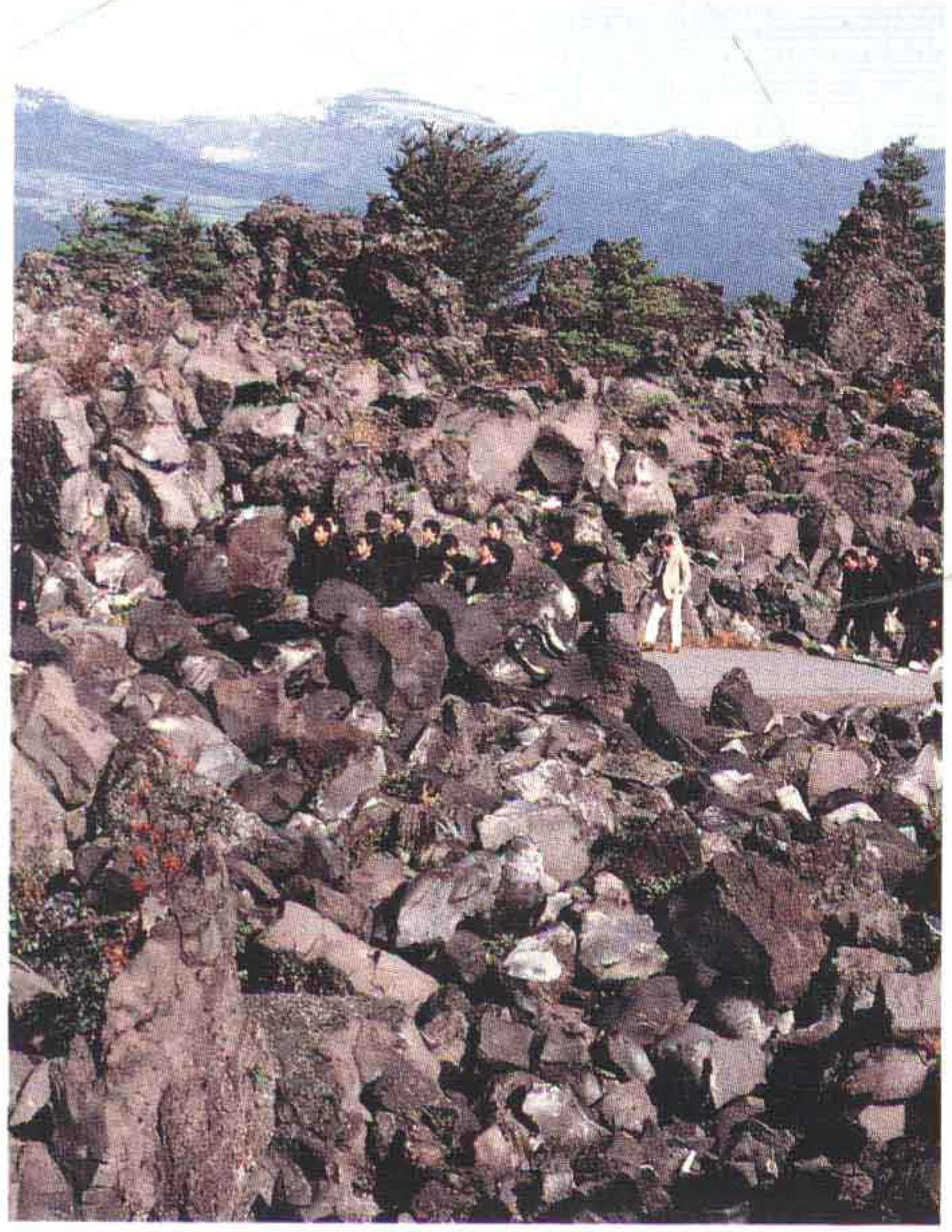
More often, the lava piles up, over and around the vent as a dome (fig 8). The dome grows over a period of weeks or even years, and may reach a height of several hundred metres. In time these domes, which are generally made of rhyolite, dacite or trachyte, become flanked by screes of fragments – 'crumble breccia'. Hot spots in the dome may be marked by spines of pasty lava, squeezed like toothpaste out of a tube. The classic example of a spine is the 300 metre one which formed on Mont Pelée during the 1902–4 eruption (p 58).

8 Tarumai lava dome, Hokkaido, Japan.

Pasty lava which is more mobile will flow down the slope of the volcano and spread out over the surrounding land at a speed of perhaps a few metres each day. The surface of the flow cools to form a thick stony skin, constantly breaking as the underlying lava moves. This happens along horizontal shear planes, so that the lava acts rather like a pack of cards being slid along. The front and sides of the flow become covered with sheared lava blocks (fig 9), which may hide the molten material altogether. The surface of the flow may be thrown into giant ridges (fig. 10), equivalent to the small wrinkles on pahoeoe lava (p 5). Flows such as this may be hundreds of metres thick, but are seldom more than a few kilometres long. Flows of pasty lava damage less property than fast, long, runny flows which can spread over greater areas.

Lava-flows rarely kill, however; all flows normally move slowly enough for people to avoid them. Lava continues to spread across level ground as long as the flow is still fed by continuing eruption. A pasty lava-flow can be very big and thick (fig 11), yet move imperceptibly slowly.

Normally, on eruption, dissolved gases burst their way out of pasty magma with explosive violence (pp 10 to 13) producing clouds of fine volcanic debris called ash. With moderately explosive eruptions, the volcano becomes more steeply conical than those formed by runny lava. The dangers in these eruptions come from the unpredictable nature of the explosions of escaping gas, which may lead to catastrophic pyroclastic-flows (p 14) and from the collapse of weak, oversteepened slopes.



9 The 1783 lava-flow, Asama, Japan.

10 Lava-flows 350–450 years old, Mt St Helens south side.

11 Five hundred metre-thick Cerros de Chao lava-flow, N. Chile.

VOLCANIC GAS

12 Bocca Nuova, Etna, 1971.

13 Bocca Nuova by night.

Volcanic gas consists largely of steam and carbon dioxide. Gases were escaping from the molten Earth surface 4.5 billion years ago, forming the atmosphere and oceans. Both free and dissolved, gases are a major ingredient of mineral deposits (p 42).

Carbon dioxide is dense; when erupted, it may collect in valleys as deep pools of gas, suffocating animals. Volcanic gases which contain fluorine, sulphur or chlorine can be very noxious. Such gases were produced by the Skaftár Fires eruption (p 55), with severe effects on vegetation and grazing animals. Sulphur commonly occurs in the form of hydrogen sulphide, giving the 'bad eggs' stench which pervades volcanoes, fumaroles and hot springs. Within the magma these gases are held in solution by pressure inside the Earth. As magma erupts, pressure drops and gases are released. Their manner of escape affects an eruption's explosiveness (pp 10, 11). At Mayon in 1968, gas separation was violent, resulting in exposive eruption (fig 14).

Continuously active, but relatively mildly erupting volcanoes such as Etna provide an opportunity to sample volcanic gases (fig 12). Even so, this is hazardous: the behaviour of volcanoes is unpredictable. Protective suits are worn against temperatures of around 1000 degrees C. A night view (fig 13) reveals the high gas temperature. Several samples are collected taking care to prevent contamination. Useful data can also be obtained by extraction of gases trapped within lava after it has solidified, and by analysis of samples from hot springs.

14 Explosive eruption with pyroclastic-flows, Mayon, Philippines, 1968.

VOLCANIC EXPLOSIONS

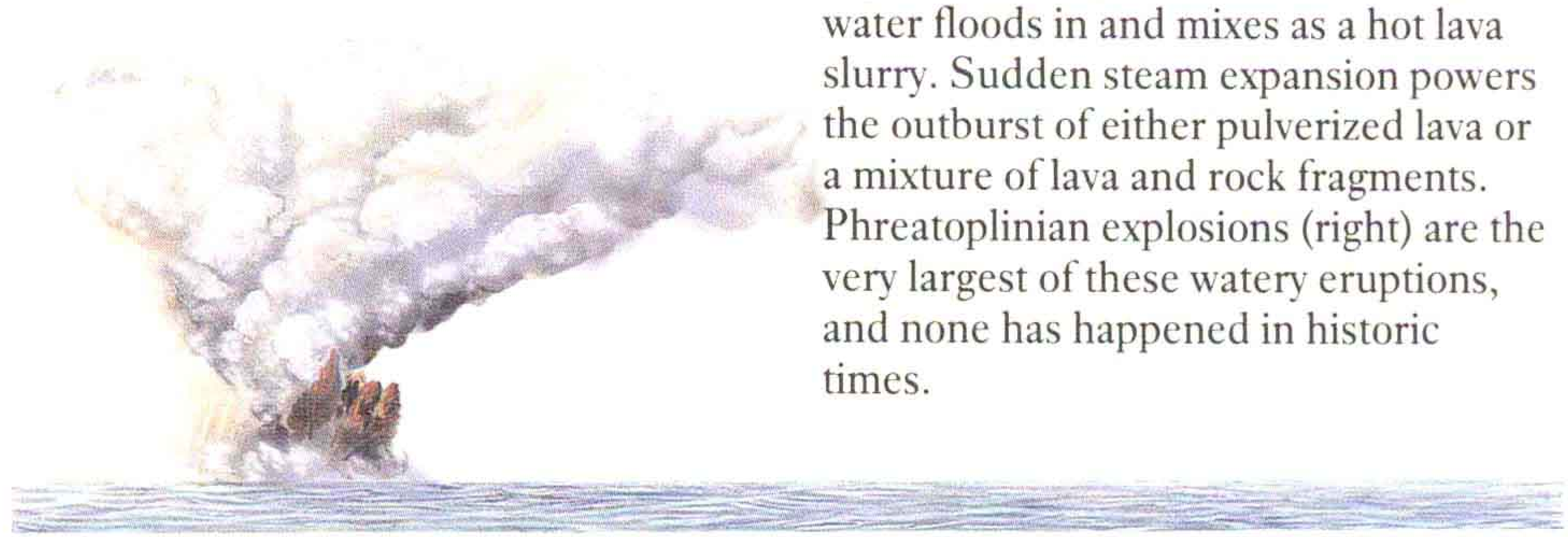
Many volcanic eruptions are explosive. Small explosions can be the size of quarry blasts. In historic times, the largest volcanic explosions have been far greater than the largest bombs ever detonated on Earth, but even these are dwarfed by some prehistoric eruptions.

Modern volcanic explosions can be compared with explosions which took place long ago. Even though there were no witnesses, what might have happened can still be worked out by observing the solidified lava and ash. By comparing these with modern day eruptions which were witnessed, a story can be pieced together for their eruption.

Although each volcano is different, explosions can be classified into various types, some called after a representative volcano or notable eruption.

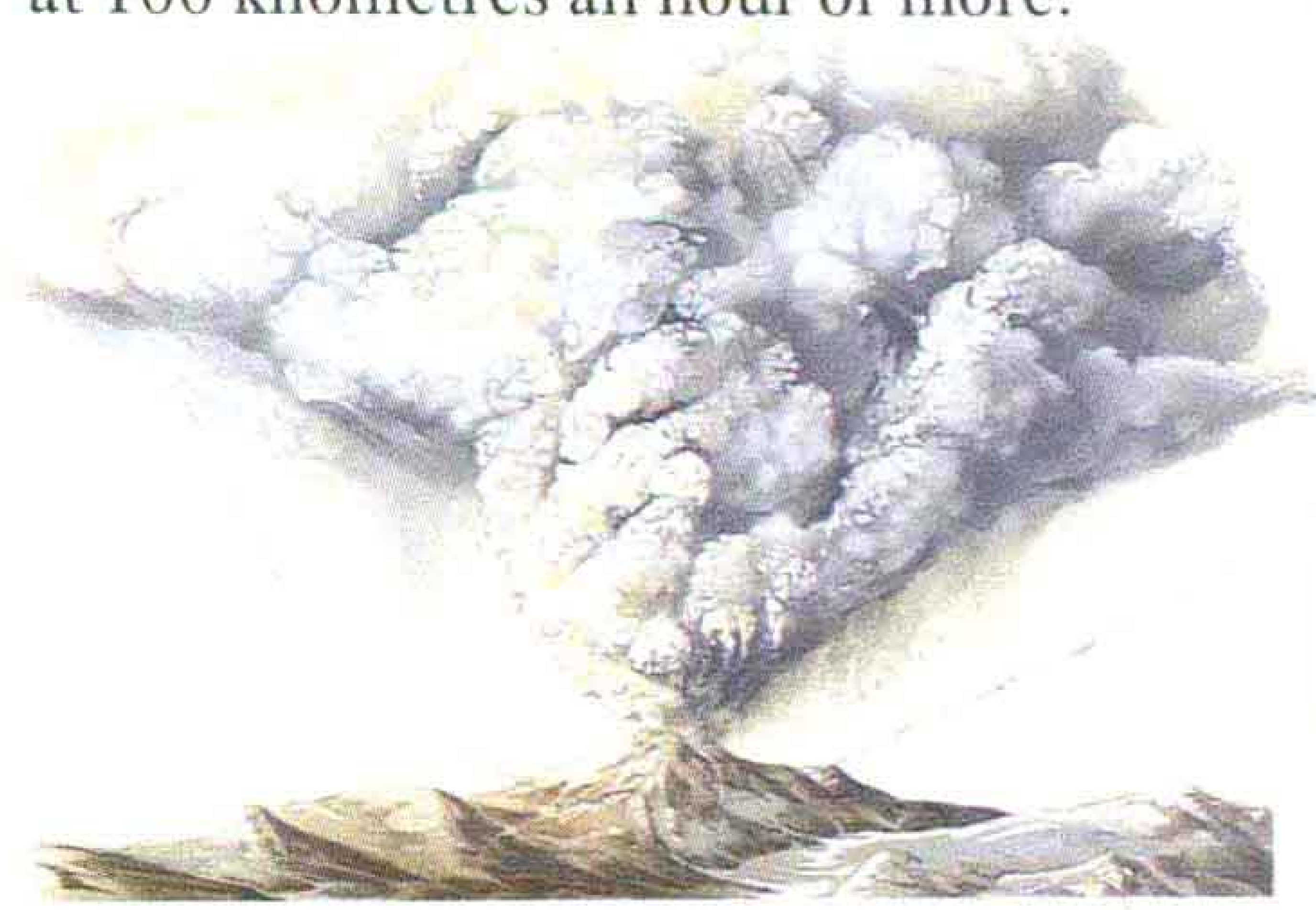
Hawaiian
Volcanic gas escaping from hot and runny basalt lava causes it to spout from a crack or hole. As the cooling lava flies through the air, it is broken up by the escaping gas. Small fragments blow away on the wind, but most are large and settle near the fountain as a cone.

Phreatoplinian & Surtseyan
Eruption into shallow water, the sea or a lake, shatters lava into tiny particles, as water is suddenly converted into steam. The eruption can be a pulsating series of explosions (left) or a continuous roar as water floods in and mixes as a hot lava slurry. Sudden steam expansion powers the outburst of either pulverized lava or a mixture of lava and rock fragments. Phreatoplinian explosions (right) are the very largest of these watery eruptions, and none has happened in historic times.

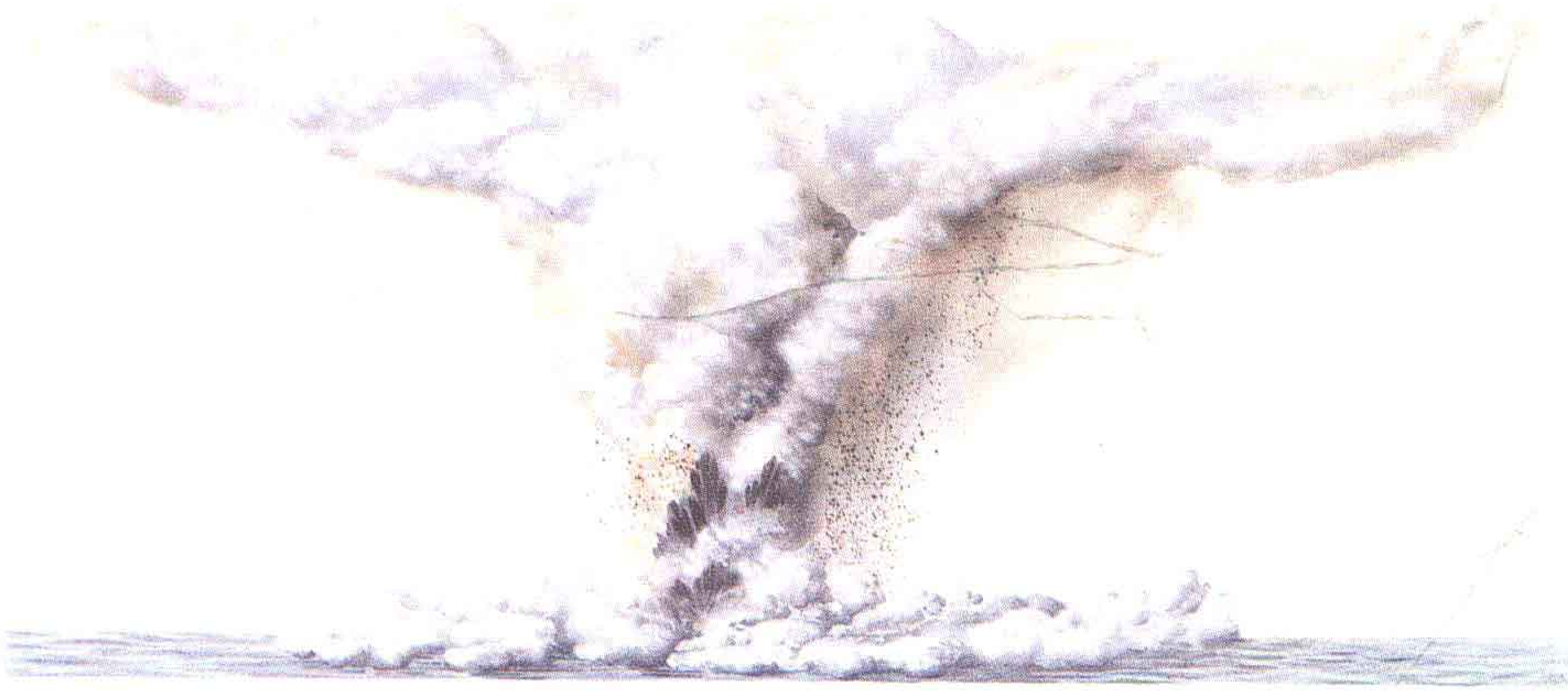


Strombolian
Frequent explosions burst from a thinly crusted-over lava pool in a crater. When a large bubble of gas rises quickly in runny magma, it bursts the solidified lava skin and explodes from the crater. Fragments of cooling lava from the bursting bubble range from dust-sized to blocks over a metre across. These are thrown out around the crater. The reddish-brown coloured fragments build up a cone, whose slopes collapse whenever they grow too steep. Explosion types are graded from Hawaiian to Strombolian and Plinian, with no distinct boundaries.

Sub-Plinian
Caused by gas foaming from magma deep in the volcano feed-pipe. These are somewhat smaller than Plinian explosions. The fragmented lava and gas is blasted to heights of up to 30 kilometres by the explosion. The explosion column may collapse back around the vent, to travel along the ground as fast-moving pyroclastic-flows, at 100 kilometres an hour or more.



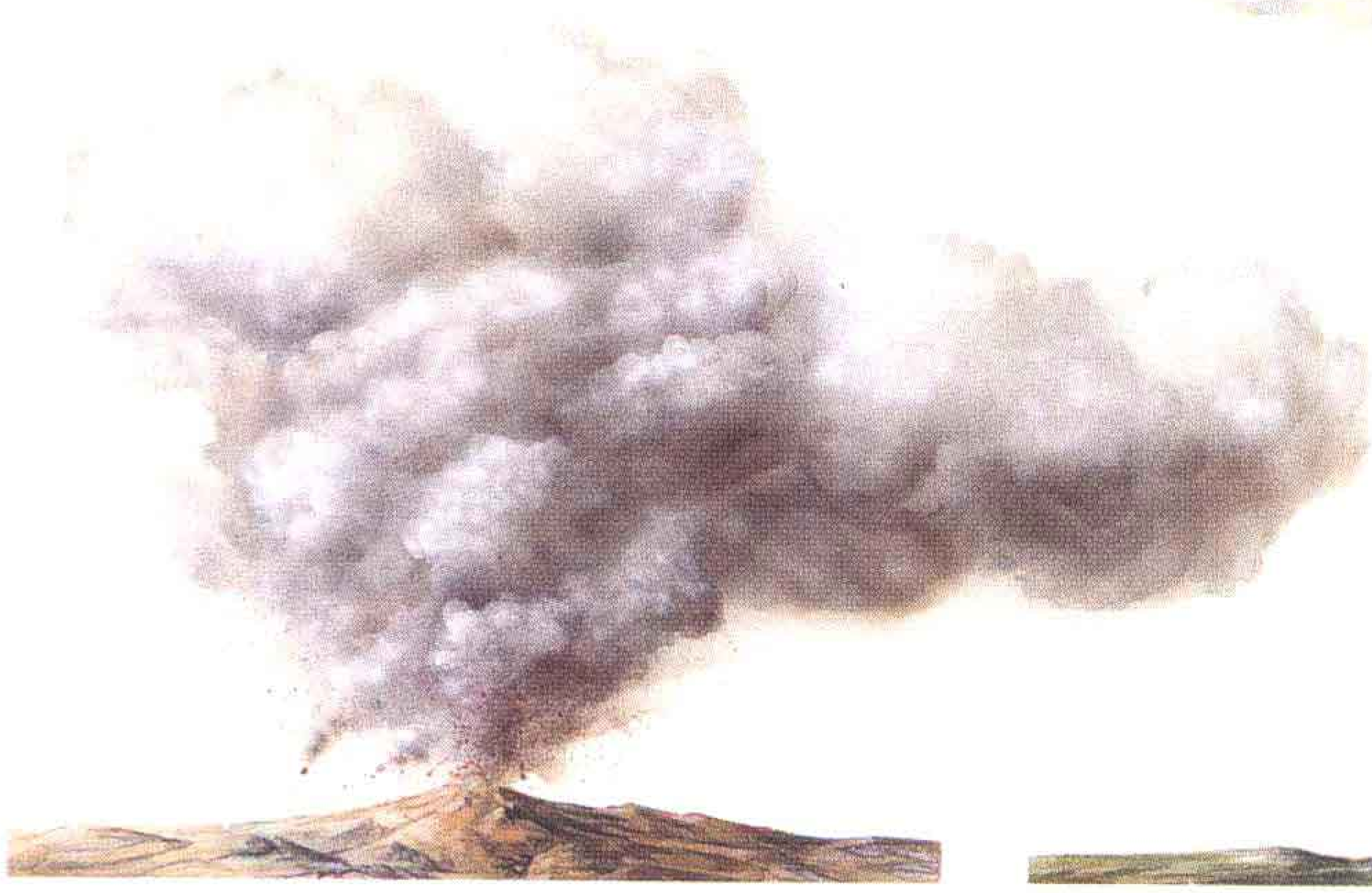
VOLCANIC EXPLOSIONS



Plinian & Ultraplinian
A high velocity explosion (below) shoots a huge column of pumice fragments up to 50 km into the upper atmosphere. This happens when gas foams up in pasty magma below a volcano. Particles settle out hundreds of kilometres around. Nearby towns may be buried within hours under several metres of pumice fragments. It may be several hundred years between one Plinian explosion and the next at one volcano.

No Ultraplinian events have taken place in historical times. Lava fragments are lofted into an explosion column more than 50 kilometres high, and small particles settle over areas the size of a whole continent.

Vulcanian
Cannon-like explosions happen at unpredictable intervals, minutes to several hours apart. An explosion (below) happens when enough gas collects under a plug of lava or rocks to blow it out, maybe even at supersonic speed. The largest fragments are thrown many tens of metres from the crater.

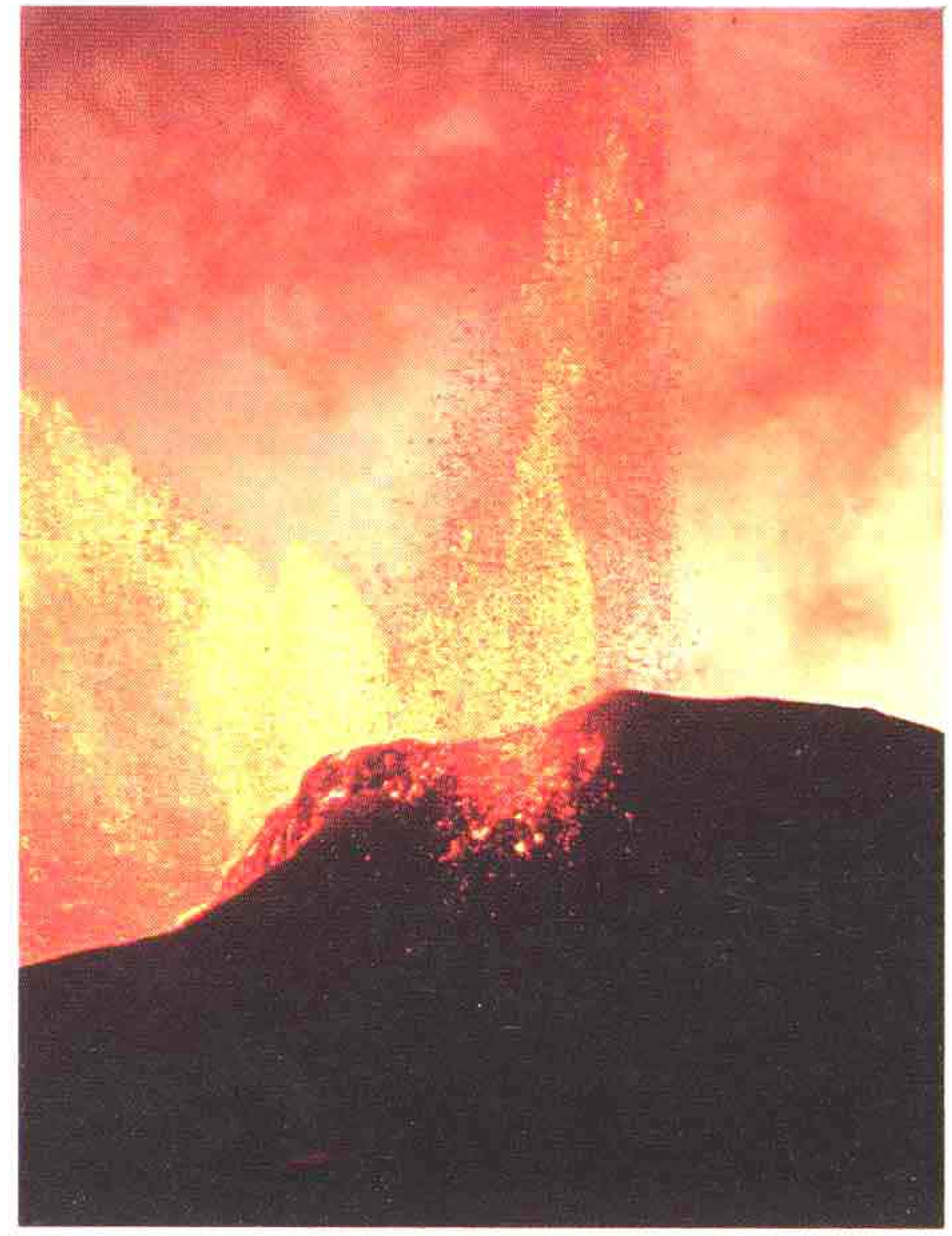


EXPLOSIVE ERUPTIONS

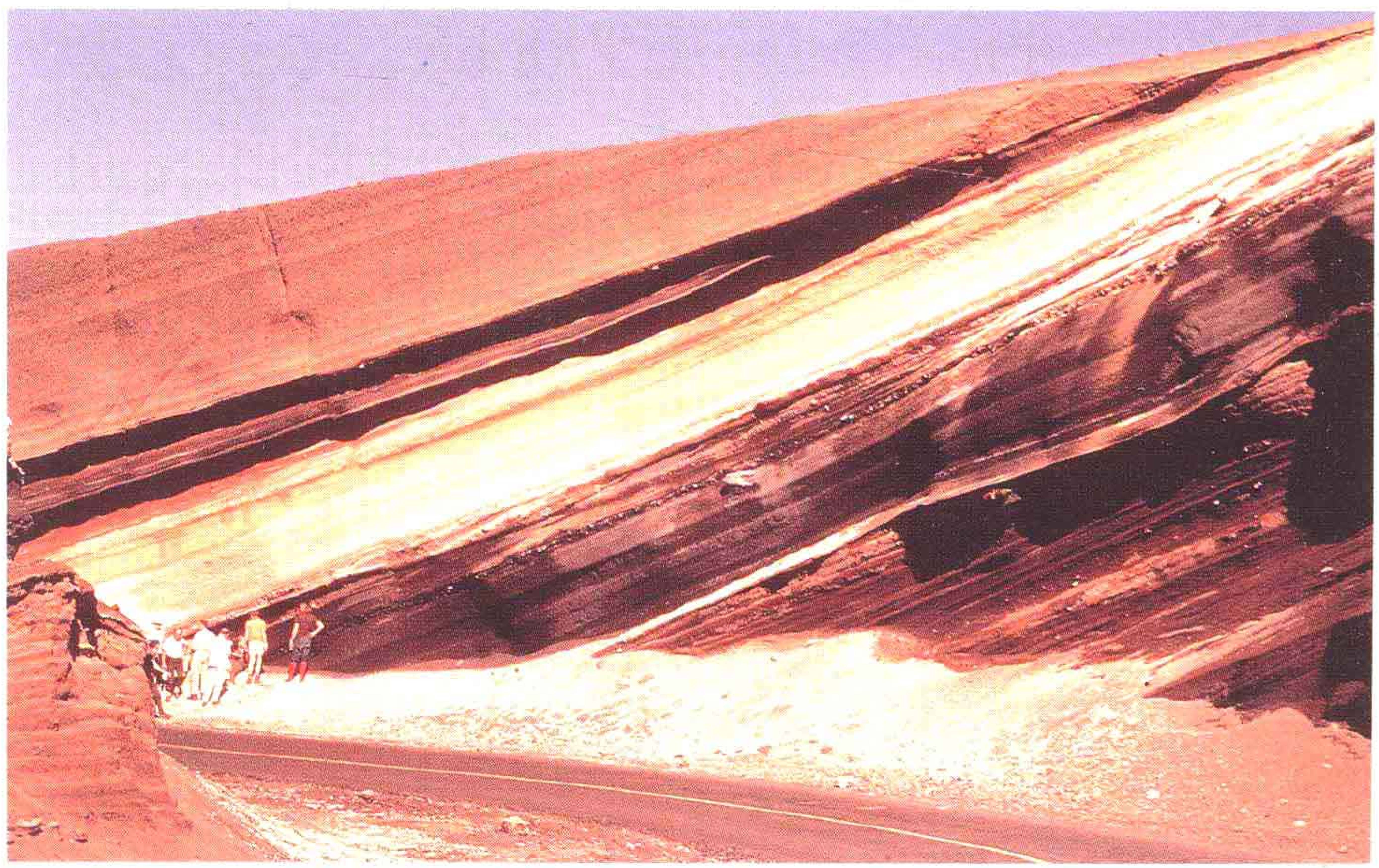
15 Ash-covered terraced fields near Galunggung in eruption, Java, August 1982.

During eruption of magma, gas may escape explosively to produce fragments, which are scattered by the force of the explosion. In mild, Hawaiian type fire-fountain explosions (fig 16), most of the fragments fall nearby. Smaller particles are blown away on the wind. Hawaiian lava is very runny; drops of liquid flying through the air are stretched out into thin threads of volcanic glass. These blow away and collect as 'Pelés hair', Pelé being the Hawaiian fire-goddess. Around small, ashy explosions, fragments fall near the vent and build up a cone. Sloping layers (fig 17) may reveal stages in explosive activity. Larger explosions involve pasty, gas-rich magma, or runny magma and water (p 20) and often produce large quantities of finely pulverized rock and lava particles. This is called 'ash' because it looks like ash from a fire, even though it has not been burned. When an explosion cloud is lofted and spreads into the atmosphere, ash can cause havoc (pp 16,17), blanketing a large area. A thin coating of ash can be beneficial, adding nutrients to the soil, but any more may be a hazard to life and property (fig 15), collapsing roofs and destroying crops, causing breathing difficulties for animals, preventing machinery and transport from working and altering natural drainage. Fragments from volcanic eruptions – 'tephra', or 'pyroclastics' – also include solid pieces of old lava as well as new lava, crystals and frothed glass ('pumice'). Pea- to walnut-sized fragments are termed 'lapilli'; larger pieces are known as 'blocks' or 'bombs'.

The blast from a large explosion sends up a column of gas and dust in a jet-thrust at speeds of as much as 500 metres per second. The eruption column suddenly expands and slows as it engulfs and heats the surrounding air. For the next few kilometres the column rises like thick, turbulent smoke from a chimney, buoyed up by its convecting heat. Above this zone, where the cloud has become similar in density to the surrounding air and the effect of the wind can take over, an umbrella of dust and gas spreads out. The total height depends on the energy of the explosion – the quantity of erupting magma and rock and the rate the eruption column rushes from the vent. Collapse of the explosion column may create a widespread flow of ash and blocks (p 14).



16 Fire fountains in Hawaii.

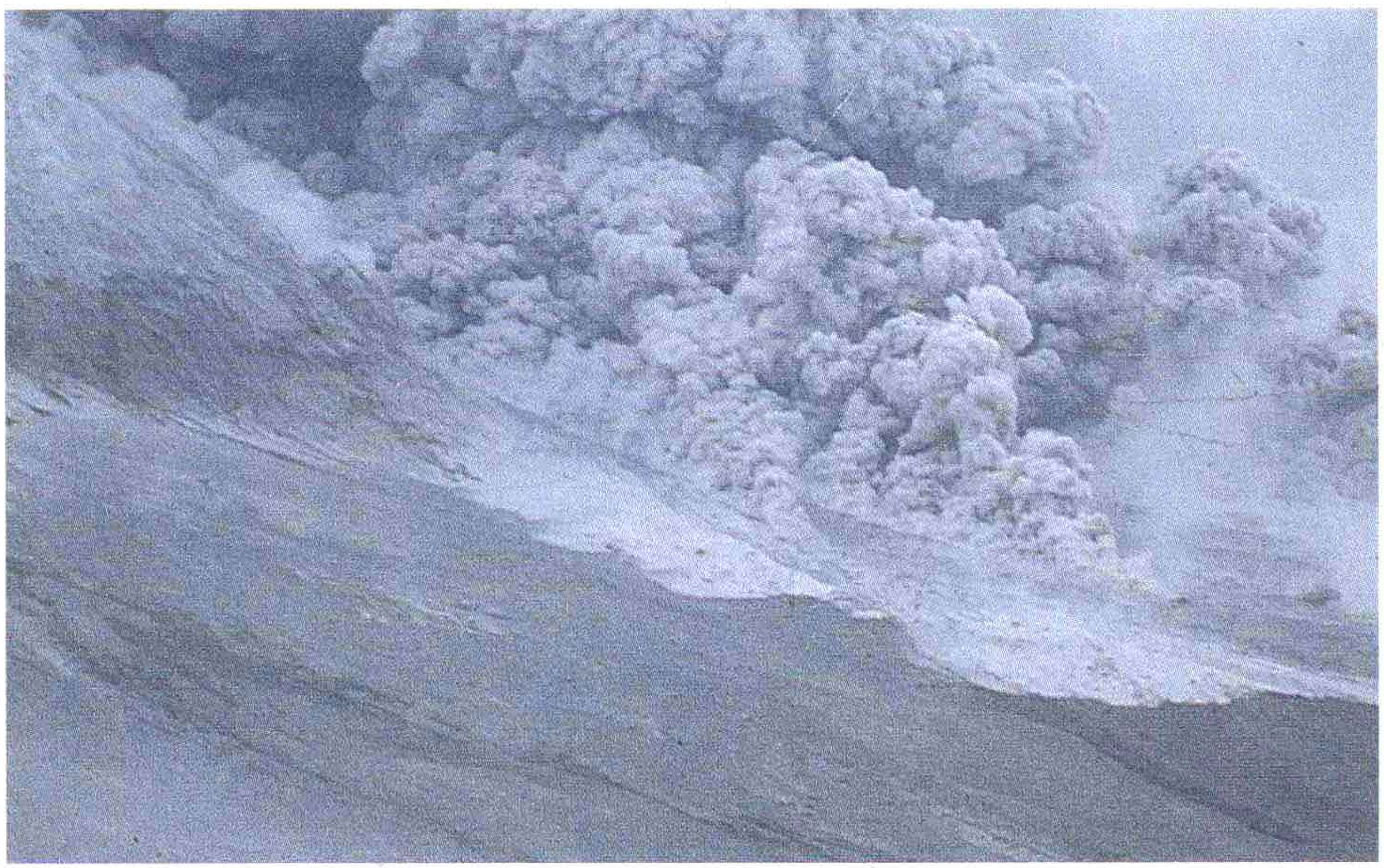


17 Ash layers, Las Cañadas, Tenerife.

PYROCLASTIC-FLOWS

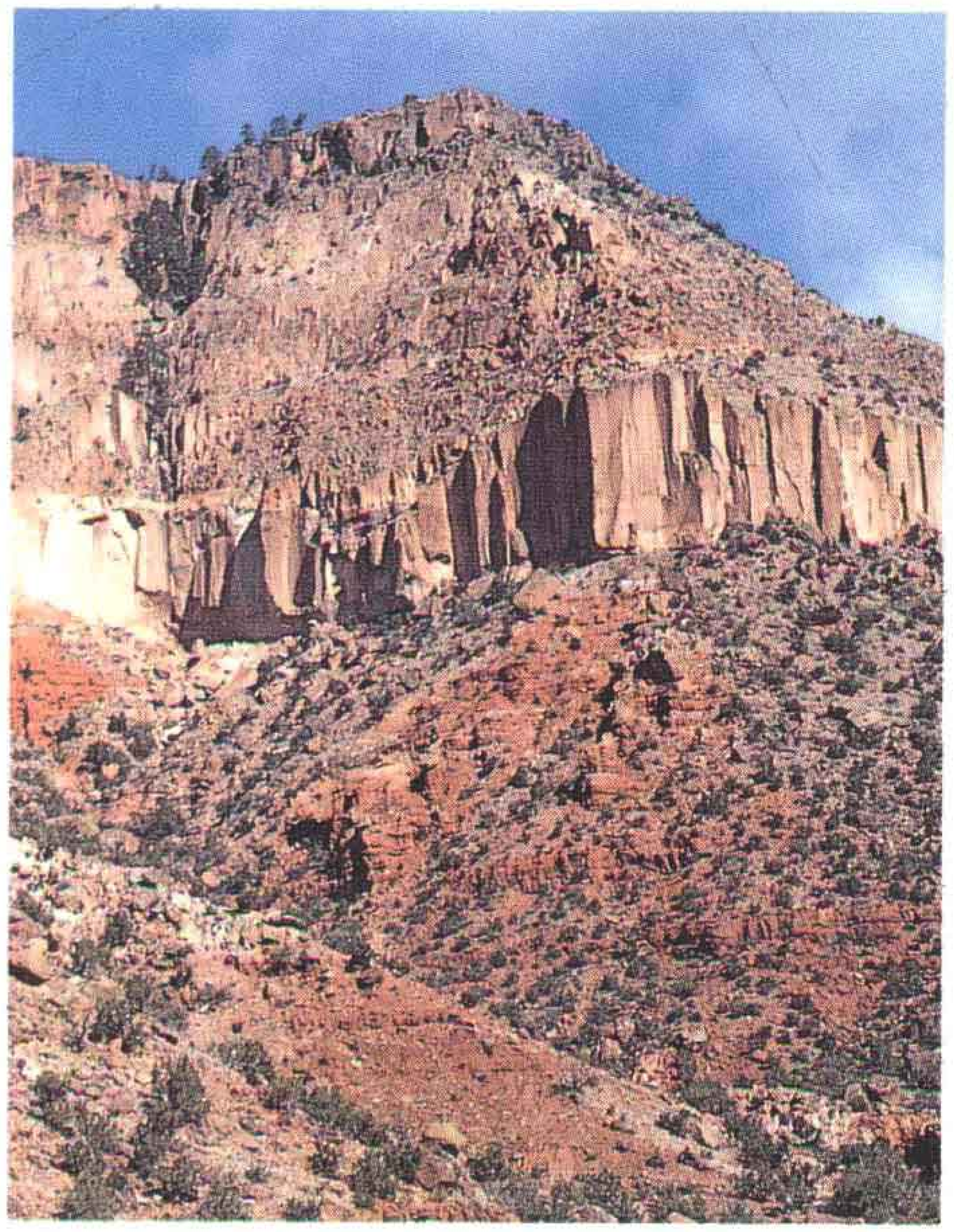
Explosive volcanoes erupt fragmented magma, ash and rocks (pyroclastics). Large explosions continue for several hours, erupting many cubic kilometres of fragments, mostly ash and pumice. Initially these are carried upwards as a billowing eruption column. The crater becomes widened by erosion of its walls: this allows more magma to froth, fragment and erupt from the reservoir beneath the volcano. The proportion of fragments in the eruption could increase, and the cloud of pyroclastics and gases cannot mix with enough air to remain buoyant. The eruption column then collapses around the vent, and flows of ash and larger fragments spread out from the eruption centre as hot avalanches which are called pyroclastic-flows (fig 18).

The way in which pyroclastic-flows travel, the area they cover, and the thickness of the pyroclastic blanket, depend on the shape and size of the vent, the volume of fragments and the rate at which they are erupted. Flows in the Valley of Ten Thousand Smokes (p 57) were erupted slowly and fill the valley to a great thickness. During part of an eruption at Taupo, 1800 years ago (p 52), over ten cubic km of magma frothed up and erupted in minutes. Flows spread rapidly in all directions and covered a huge area quite thinly. Yet, in the immensity of the Earth's geological record, the Taupo eruption was merely medium-sized. The largest pumice-rich pyroclastic deposits, known as ignimbrite, would have covered areas greater than that of England, with volumes of up to 3000 cubic km.

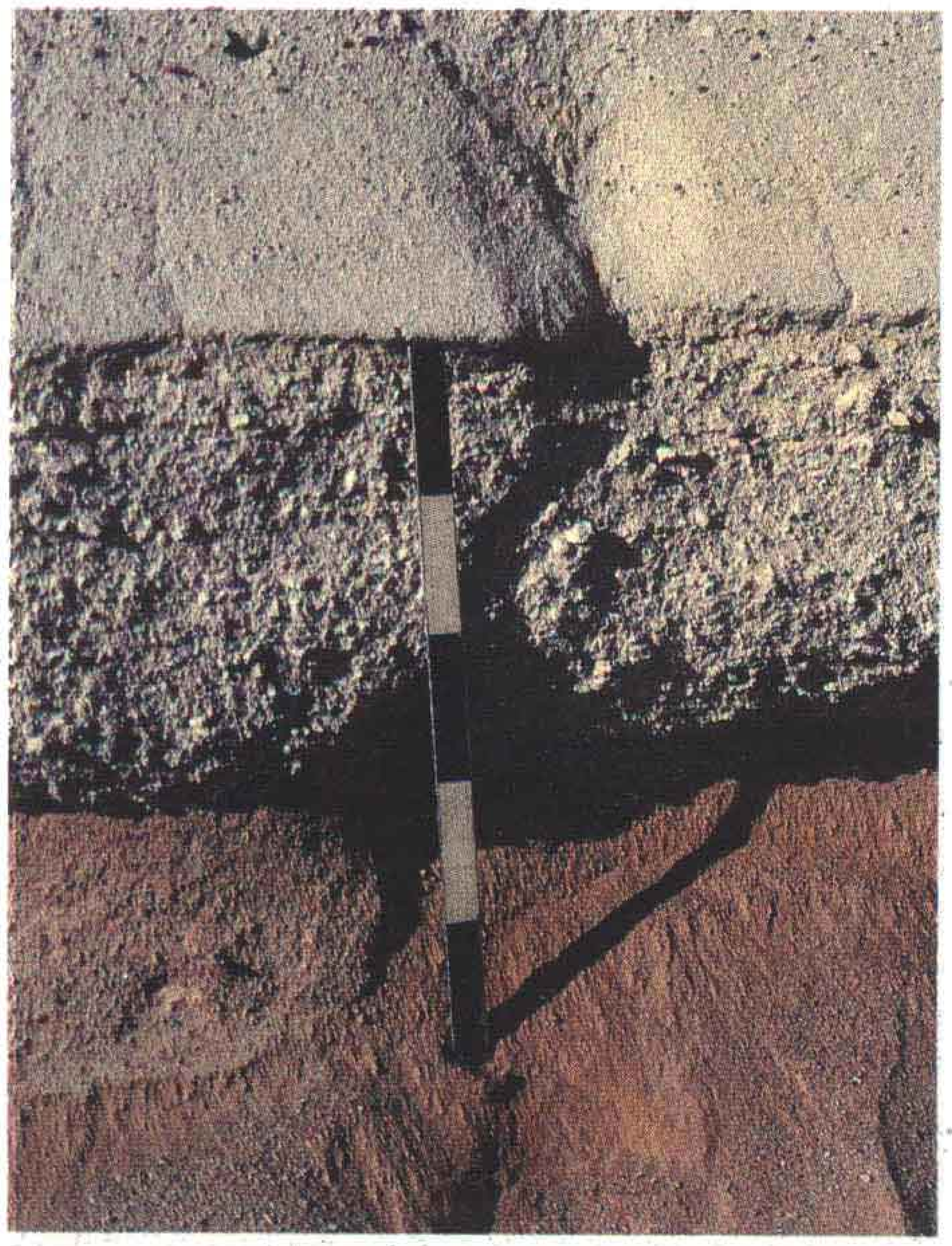


18 Pyroclastic-flows at Augustine, Alaska.

Pyroclastic-flows are sometimes preceded by a fast-moving surge, a hot blast of fine-grained ash. Fig 18 shows a surge travelling in front of a pyroclastic-flow. The fine ash layer left by a surge is easily eroded by the first rain that falls after an eruption; such ash is rarely seen. The surge can scorch and fell trees. The pyroclastic-flow itself moves at up to 200 kilometres an hour. It carries unsorted fragments from fine ash to large blocks a metre or so across. If it is hot when it comes to rest, then the ash may be welded into solid rock. Large flows normally contain pumice, solidified pieces of frothed magma. Sometimes the ash is cemented by percolating waters a long time after deposition. In fig 22 pinnacles of ash can be seen: these surround parts of a pyroclastic-flow deposit cemented by minerals from rising hot waters or gases. The softer, uncemented material has been worn away. In trying to work out how the eruption looked, geologists have only fragments of evidence to work with. Fig 19 shows ignimbrites from two eruptions which took place three hundred thousand years apart. The lower layer has an irregular top surface: erosion has carved away swathes of ash, leaving pinnacles. The next eruption filled in the hollows. Over thousands or millions of years, repeated pyroclastic-flow eruptions may build up a level plateau (fig 21). The whole plateau, together with a huge, often lake-filled depression at the eruption site, can be thought of as a 'volcano' even though this is very different from the cone-shape so often depicted in diagrams and photographs (see pp 22–23).

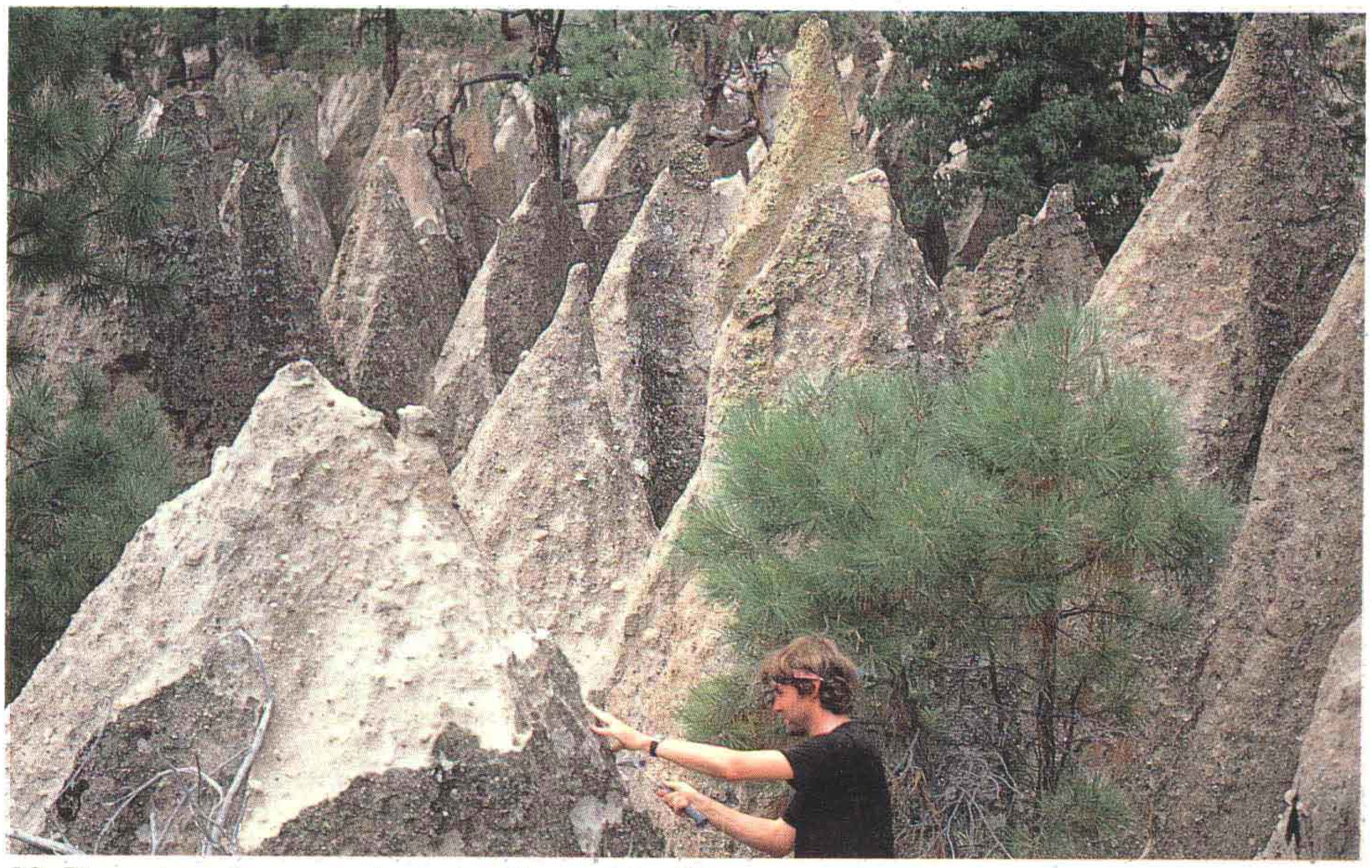


19 Bandelier Tuffs, New Mexico.



20 Ignimbrite on ash and soil.

21 Plateau formed by the Bandelier Tuffs, San Diego Canyon, New Mexico.



22 Pinnacles of cemented ash, La Cueva, New Mexico.