Man and Volcanoes: The Benefits

Early traces humans left in East Africa about 3 million years ago are footprints in volcanic tuffs (Fig. 15.1). It is as if man had walked through a thin layer of freshly poured-out concrete that subsequently hardened to the benefit of posterity and anthropology. Seen in historical perspective, volcanoes are a threat to people, commonly only for very brief periods. Exceptions are places, such as the city of Kagoshima on the southern tip of the Japanese island of Kyushu, with its almost daily rain of ashes from the nearby almost permanently active volcano Sakurajima. The custom to dry clothes in the garden thus never developed in Kagoshima. In general, however, man has always benefited very much more from volcanoes than suffered from their eruptions. The undeniable benefits of volcanoes range from obsidian tools used in many early cultures, caves that can be dug easily in massive tuffs, fertile soils, attractive landscapes to geothermal energy. It is little known, for example, that a modern city such as San Francisco, receives the bulk of its electric energy from a young volcanic area, the Geysers, a couple of hours by car north of the Golden Gate metropolis.

▲ Fig. 15.1. Footprint of a Polynesian in ash, which had just been deposited wet and warm after the phreatomagmatic eruption of Kilauea volcano in 1790 (?). The footprints are well-preserved on the dry southern flanks of the volcano

The immense benefit man draws from volcanoes will be discussed below under five headings: heat from the Earth, volcanogenic ore deposits, volcanic soils, volcanic raw materials and volcanic landscapes.

> **Like passion, whose emblem it is, it can die**
> *Susan Sontag, The Volcano Lover, New York, 1993*

Heat From the Interior of the Earth

To exploit the heat in volcanic areas is nothing new to countries such as New Zealand, the Philippines, Iceland, Italy or Mexico (Fig. 15.2). The rising energy needs in modern society (even if more slowly than predicted only a few years ago), the decreasing supplies in valuable fossil gas and oil, the CO_2 emission of coal power plants, and the obvious problems of nuclear energy (especially the difficult problem of long-term storage of nuclear waste) all have spawned an increase of basic research into alternative forms of energy. The search for geothermal deposits and those metallic deposits that occur around magma chambers has thus been accelerated – and it is hoped that this energy can be utilized without losing sight of a sustainable environment.

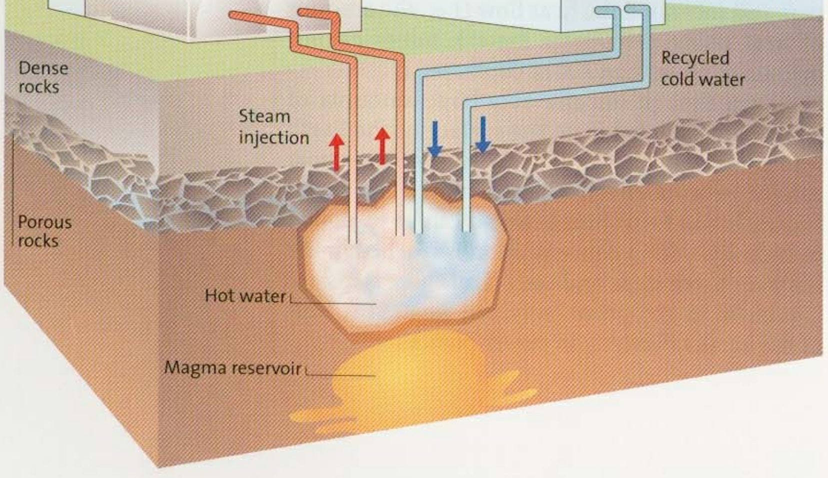
Geothermal Energy

Temperatures increase from the surface of the Earth toward its interior. For example, it is getting warmer when one enters a mine, but not everywhere at the same rate. Mining can be carried out at depths greater than 3 000 m in southern Africa, an old continental shield where the heat flow is low. In areas of active tectonism or volcanism, however, the same temperature is reached much closer to the surface. In young rift zones as along the upper Rhine graben, where hot mantle material has risen from depth in the recent geologic past and increased the heat flow (i. e., the amount of heat rising per square meter), mines cannot operate at more than 800 m depth.

Even though unbelievably large amounts of energy are radiated from the surface of the Earth into outer space each day (ca. 10^{12} J/a) this heat cannot be used effectively as a source of energy. Nature has to focus heat before it can be exploited technically. Such a concentration is reached in the Earth in three steps and only if all three steps are combined in an optimal way, can we use the heat of the Earth effectively in power plants.

▲ Fig. 15.2. Geothermal power plant at Wairakei (New Zealand)

▼ Fig. 15.3. Schematic cross section through a geothermal system. Water circulating in porous rocks is heated and rises as hydrothermal water to the Earth's surface (hot springs, geysers) or is utilized in geothermal power plants (269)



The first step is speculative, but theoretically probable. As discussed in Chapter 2, we can assume that the Earth mantle convects. Hotter parts rise from greater depths (as in mantle plumes, Chap. 6), so fast that they do not lose their heat en route; colder lithosphere sinks along subduction zones into the interior of the Earth (Chap. 8).

The second step is the partial melting of convectively rising and thereby decompressing mantle rock. If sufficient magma has collected in some areas, it can detach, rise and may accumulate in magma reservoirs in the upper part of the Earth's crust. This concentration of heat (magmas with liquidus temperatures of 750–1 200 °C in a continental surrounding of 80–300 °C, 3–10 km beneath the surface), is in itself not focused enough. This is so because the conductive migration of heat in well-insulating dry rock is much too slow and too diffuse to be utilized technically.

The most efficient transport of heat is by fluids, such as magma or water. In the upper crust of the Earth, the mobile fluid is groundwater that circulates in pores and fractures. When heated above a magma chamber or a cooling, still hot, crystallized magmatic body, its density decreases, enabling the hot water to rise into the upper crust or to the Earth's surface (Fig. 15.3). This is apparent in many areas of young volcanism in the form of hot springs, or the often spectacularly erupting geysers. To be used in the form of energy, one also needs pressure. This condition is reached when the water, heated above its boiling point, cannot expand beneath a dense impermeable layer of rocks, such as clay-rich sediments. When drill holes are sunk through such an impermeable layer, the steam, which, depending on the temperature and pressure, is either dry (i.e., free of condensed water) or wet, can expand according to its temperature either directly in turbines, or through heat exchangers.

The utilized geothermal energy in power plants is thus dependent on a combination of several geological processes. This includes focusing of heat in the form of magma and transport into the upper part of the Earth's crust. The other necessary condition is plenty of water and permeable rocks, in which the water can circulate. In most current geothermal power plants, the heat source is a documented or assumed magma chamber in the upper crust. Well-known geothermal power plants are in areas of young volcanism, such as the Geysers in California (2 000 MW); Iceland (590 MW) – ca. 50 % of the country's energy consumption; Wairakei, New Zealand (250 MW) (Fig. 15.2) and Larderello, Italy (530 MW).

The larger and younger a magma chamber and the closer it is to the Earth's surface, the higher its geothermal potential. The presence of such young magma chambers must be inferred either indirectly through geological-petrological studies or via remote sensing, such as gravimetry. Examples are:

- negative gravity anomalies above SiO_2-rich and thus low-density magmas
- increased conductivity because of the presence of magma or hot rocks
- microseismicity around young magma chambers.

Because the solubility of minerals generally increases with temperature, chemical geothermometers have been developed to infer the temperature at the origin of hydrothermal systems. A well-known geothermometer is the ratio of the elements Na/K/Ca with corrections for Mg and SiO_2. Light stable isotopes, during the last few years, were central to the discovery that a large part of the water in hydrothermal systems is of meteoric and not magmatic origin. In addition, high $^3He/^4He$ ratios indicate magmatic sources (mantle degassing).

Locally, one does not need young magma chambers to utilize the heat of the Earth. In thick, porous sediment series, with a regional or slightly elevated geothermal gradient, water can penetrate to greater depths and rise as heated hydrothermal water convectively in the pores of sediment or along fractures or faults to the surface.

Well-known heat anomalies in central Europe, where warm groundwater is used for space heating or for hot baths, are the Pannonian Basin in Hungary, Urach and Upper Rhine Valley in Germany, and the Paris Basin in France. Research into the geothermal potential of young magma chamber systems has been intensified in many countries. In addition, research has been carried-out where cold water is pumped into hot dry rock systems along artificial fractures, where it circulates, becomes heated, and rises back to the surface.

Geothermal energy will play a significant role in the near future only in areas with abundant young volcanism, apart from hot springs (Figs. 15.4, 15.5). Only when the costs for fossil fuel become too high, or if the CO_2 and SO_2 emissions of

▲ Fig. 15.4. Eggs boiled for tourists in fumaroles. Atosanupuri dome volcano (Kutcharo caldera, Hokkaido, Japan)

▼ Fig. 15.5. Sinter terraces in the geyser area of Mammoth Hot Springs (Yellowstone National Park, Wyoming, USA)

▶ Fig. 15.6. Former copper mine in submarine lavas of the Cretaceous Troodos ophiolite complex (Mitsero, Cyprus)

coal power plants become critical, or the hazards and problems of nuclear power plants or their acceptance in society have reached critical threshold values, will the exploitation of the natural heat supply of nature be utilized either in the form of hot water from depths or through the hot dry rock process.

Many magma chambers occur at shallow crustal depths (2–4 km) beneath mid-ocean ridges. The search for such magma chambers by seismic and other methods has been very difficult, however, and well-documented magma lenses have so far been found only in a few areas along the East Pacific Rise (Chap. 5). Their technical utilization is still a matter of science fiction, apart from the problem of transporting the energy over large distances or moving industry from the continents to the middle of the oceans. On the other hand, the enormous heat supply of mid-ocean ridge magma chambers has powered a fundamental recycling machinery during Earth history. Many important ore deposits on Earth were generated by streams of hot water continuously circulating through the young and hot ocean crust in the middle of the oceans.

Hot Water Valves on the Ocean Floor and the Formation of Ore Deposits

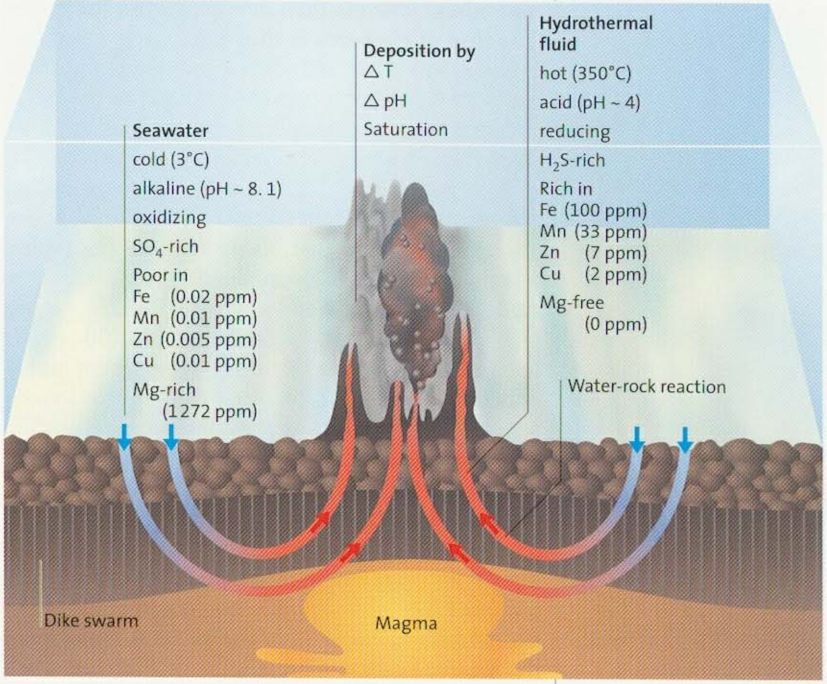
Volcanogenic ore deposits have been the fundamental economic base in many countries for thousands of years. Three characteristic types of deposits are known from present day mid-ocean ridges. The first type is rich in iron and manganese, the second only in manganese and the third is rich in sulfides and poor in manganese. The first, most common type, commonly forms deposits at the base of oceanic sediments above the volcanic crust. The third type is the most spectacular one, because it forms through the hot water chimneys, called *black smokers*, on mid-ocean ridges but also on active seamounts.

One of the most exciting and important discoveries in geology during the last few decades was the finding of black smokers on the East Pacific Rise in 1977 (206). A diving expedition of "Alvin" found a group of round chimneys about 10 m high and up to 0.4 m wide, about 1 000 km north of the Galapagos Ridge. These not only consisted entirely of ore minerals, but were conduits, rapidly (2–3 ms^{-1}) emitting hot hydrothermal water into the cold seawater (206). At the exit of the hot water, dense clouds of dark sulfide crystals, ore minerals, especially iron, zinc and copper sulfides formed, the reason for calling the vents black smokers. The ore minerals rained out from the hot water fountains emitted from the chimneys formed small hills. The faunal associations around the chimneys, especially the *blood worms* (a new phylum in the animal kingdom), *giant clams* and *giant crabs* were part of a biological community that had developed completely anaerobic and outside photosynthesis. The assumption is that chemosynthetic bacteria oxidize H_2S emitted from the chimneys to elementary sulfur and sulfate. This oxidation generates energy that helps to incorporate CO_2 into organic compounds. The more complex organisms in turn feed on these bacteria.

The importance of this discovery is not minimized because it had been in principle predicted. In the early 1970s, some scientists noticed that the heat flow values measured along mid-ocean ridges were much lower than expected. They explained this discrepancy by postulating that cold seawater penetrated the permeable and porous volcanic crust to a depth of several km (196). The hypothesis was that seawater flowed downward into the crust over large areas, but resurfaced after being heated close to magma chambers in a focused manner. Apparently, the downwelling, initially cold seawater is not only heated when circulating close to hot magma pockets, but also becomes acid, and transforms into *hydrothermal solutions* up to about 350 °C hot when resurfacing at the seafloor. These hot and acid solutions corrode the rock through which they rise and become enriched in elements such as zinc and copper. At the orifice of the chimneys, the hot solutions are quickly cooled, become oversaturated and precipitate ore minerals, chiefly sulfides (Figs. 15.7, 15.8). In classical mining areas, such as Cyprus, an island that owes its name to the mining of copper (Latin: *cuprus*) during the time of the Phoenicians, these ore deposits occur in uplifted ocean crust, ophiolite complexes (Chap. 5, Fig. 15.6). These ore deposits are vivid expressions of the interaction of seawater that has penetrated the volcanic crust to a magmatic heat source and reappeared on the seafloor. The similarities between the processes postulated for present ocean crust-forming processes and the frozen effects in the fossil oceanic crust on Cyprus were impressive, although direct proofs were still missing.

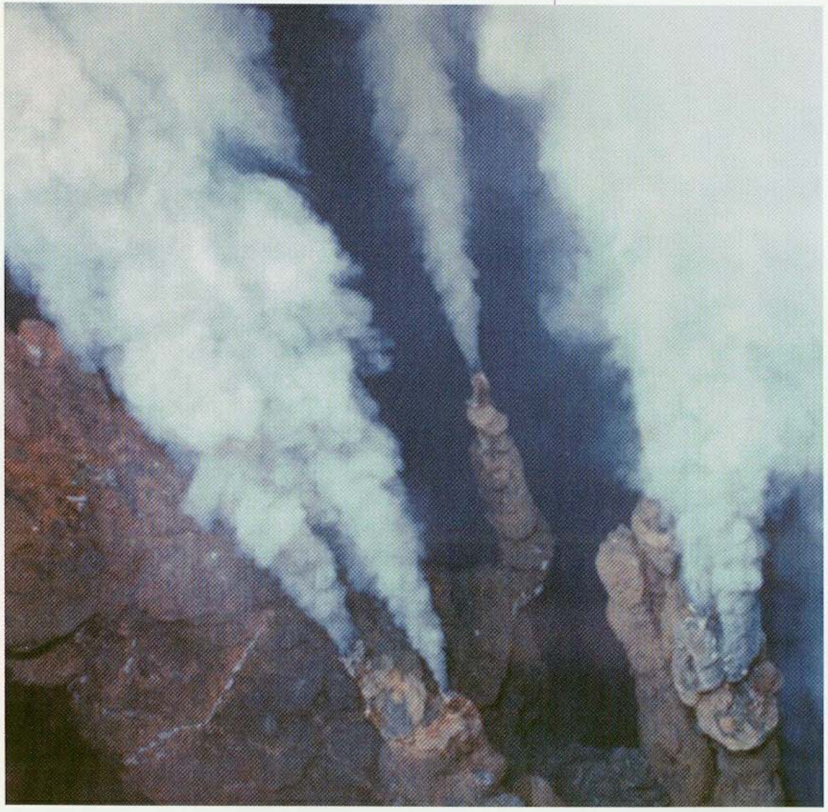
Hydrothermal vents on the seafloor are thus places in which heated water exits. Massive sulfides are deposited first, whereby the hydrothermal solutions are impoverished in Cu, Ni, Cd, Zn, Hg, S, Se, Cr and U. Manganese crusts form subsequently by deposition from cooler oxidizing solutions, which only contain a few percent of the original hydrothermal solutions. Sediments enriched in iron and manganese form at relatively low temperatures.

The fundamental importance of black smokers goes much beyond explaining the formation of ore deposition. For several years, scientists had noted that elements supplied to the oceans by rivers and deposited in clastic and chemical sediments in the oceans were not in equilibrium. For example, rivers transport more Mg, S and K into the oceans than is fixed in the sediments. On the other hand, sediments contain more Ca, Mn, Cr



▲ Fig. 15.7. Scheme of hydrothermal circulation on a mid-ocean ridge (318)

▼ Fig. 15.8. White barite-rich smoker exiting at more than 300 °C from a vent in the Lau Basin. Photo courtesy Yves Fouquet



and other elements than delivered from the rivers. The flux of elements is thus not restricted to this system, but also includes the volcanic oceanic crust. Many different reactions occur in the black smokers at high temperatures, as predicted by some experiments. The temperatures of the hydrothermal waters, exiting at mid-ocean ridges (pressure at this depth 250 bar), cannot rise above about 390 °C, and just above magma reservoirs, which are about 2000 m deeper (pressure here ca. 450 bar), not above about 465 °C. At higher temperatures at these pressures, the liquid seawater would turn into a salt-poor vapor and a highly concentrated brine (25). According to these studies, the critical point for seawater is at 403–406 °C and 285–302 bar, appreciably above that of pure water (Chap. 12). The amount of heat removed in the black smokers from the underlying hot rock is so large that the lifetime of these chimneys is only about ten years. Indeed, active chimneys are surrounded for some distance by cooled and broken up chimneys, along with the skeletal remains of the bizarre faunas.

That many widely distributed sulfide ore deposits, which contain Fe, Cu, Zn, but also Pb, Au, Ag and other elements, form from hot watery, hydrothermal solutions, around magma chambers had been postulated for decades. Nevertheless, one had assumed for some time that the hot water was directly derived from the magma, whose slow crystallization into mostly water-free crystals resulted in a concentration of water in late solution, which would penetrate along fractures into the roof and there crystallize during cooling. According to present-day knowledge, the elements of such ore deposits are scavenged by leaching from the country rock traversed by heated-up external water or a mixture of magmatic and external water. This is another example of the encounter of the elements fire and water, triggering a chain of complex feedback mechanisms, similar to phreatomagmatic eruptions (Chap. 12).

Not all *hydrothermal ore deposits* can be explained by reactions between the heat of a magma and external water. The concentration of elements such as molybdenum, tungsten or tantalum in some continental ore deposits is much too large to be explained by leaching from the country rock. Such ore deposits are especially common around granite plutons, slowly crystallized magma bodies. The ores hence not only owe their heat energy to the magma, but also their element concentration and part of the water needed for transporting the elements.

Mining of the submarine massive sulfide concentrations, formed along mid-ocean ridges at intermediate and fast spreading rates (e.g., 284), in the near future is doubtful. Such an enterprise not only depends upon an upturn in world market prices for metals, but also on complex national jurisdictions. Up to which distance from a coast can the mining rights be extended? Apart from the political and technical issues there are also major ecological problems associated with a possible submarine mining endeavor.

Volcanic Soils

Tourists who land on the airport of Gando on Gran Canaria or the Aeropuerto Reina Sofía on Tenerife (the two largest of the entirely volcanic Canary Islands), directly proceed to Playa del Ingles or Playa de las Américas and only move between their bungalow and the beach, may think the idea that volcanic soils are very fertile is a myth, upon seeing the desert-like hinterlands. This is true in so far as nothing much can be seen of volcanic soils on these dry southern slopes. Nevertheless, when visiting the green northern side of these islands, where the trade wind clouds generally park around 800 m a.s.l., this view is drastically changed. A similar situation is encountered in Hawaii, where the contrasts between Kona and Hilo sides of the Big Island are even more staggering. The southern side of Kilauea volcano is a dry lava desert, to the enjoyment of geologists and tourists. 100-year-old lava flows look as if they were erupted yesterday.

There are plenty of volcanoes in Iceland, the entire small continent is volcanic. In fact, there is so much volcanic heat in Iceland that one can even grow bananas in geothermally heated greenhouses. On the other hand, there is a lot of rain in Iceland, much to the dismay of tourists. But the volcanic soils on this big island in the northern Atlantic are skeletal or raw, because it is simply too cold for soil-forming chemical and biological processes to proceed rapidly.

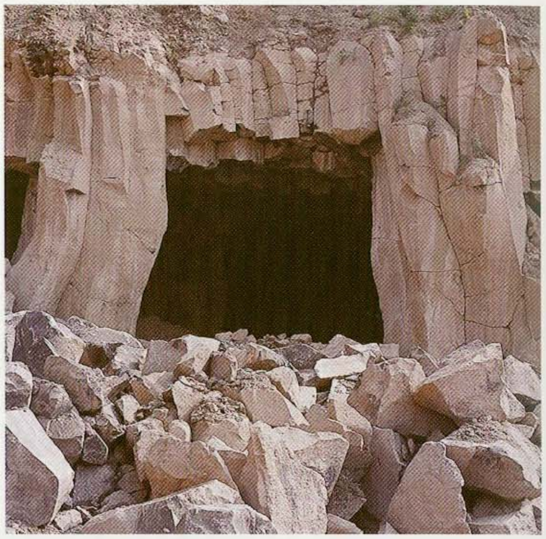
Volcanic deposits, especially ashes (weathering of lava flows takes of course much longer), have three properties to which they owe their exceptional quality as parent material for fertile soils. For one, ash particles are quite porous, especially larger lapilli. They hold moisture much longer than many other soils and release water slowly to the roots of the plants. These unique properties are frequently used to advantage in dry areas, such as the eastern Canary Islands. Basaltic lapilli, locally called *picón*, are spread on the fields, where they catch the moisture from the low clouds at night and release them peu à peu (Fig. 15.9). A second useful property of volcanic ashes is their enrichment in some elements, e.g., S, Mg, K, especially the high concentrations of some trace elements such as Se. This rich supply of nutrients can be an important boost for the growth of plants. The third factor is the glassy nature of the quickly cooled volcanic particles. Glass is thermodynamically unstable and alters relatively rapidly in the presence of water and in the right climate to crystalline and short-range-order phases, especially to clay minerals, the main mineral constituents of soils. Glass of lapilli or ash particles quickly becomes hydrated at its surface and is eventually converted to Al and Fe/Mg hydroxides. These secondary mineral surfaces and hydrated glass hold strongly onto water. All these factors, together with the humic acids of the dying plants, are the prerequisites for the Garden of Eden that is so fascinating in many volcanic areas (Fig. 15.10).

All these prerequisites: volcanic source material, warm climate and rain are present in many volcanically active areas, such as Indonesia, the Philippines or Latin America. But herein also lies a big problem. The high population pressure in developing countries forces people to move higher and higher on the fertile slopes of volcanoes, also the active and dangerous ones. Thus, many people have died during eruptions of volcanoes, such as Mount Mayon, Agung or Merapi, or have their properties destroyed in areas that actually should be closed to settlements.

▲ Fig. 15.10. Rice fields on the slopes of Merapi Volcano near Yogyakarta (Java, Indonesia)

▼ Fig. 15.9. Typical landscape on Lanzarote (Canary Islands). Pleistocene weathered scoria cone in the background. The half-moon-shaped walls made of pieces of basaltic lava protect the grapes against the wind. The black lapilli store the condensed water during the night when clouds pass over the island

▲ Fig. 15.11. Mural at entrance to road metal company in Masaya (Nicaragua) mining basaltic lapilli



► ▲ Fig. 15.12. Entrance to one of the many subterranean tunnels in the lava flow at Niedermendig (Laacher See area). For several hundred years, millstones were cut underground from this lava and were exported throughout Europe

Volcanoes as Source for Raw Materials

Scoria cones and basaltic lava flows are mined in many areas for aggregates to serve various purposes, some highly specialized (Figs. 15.11–15.13).

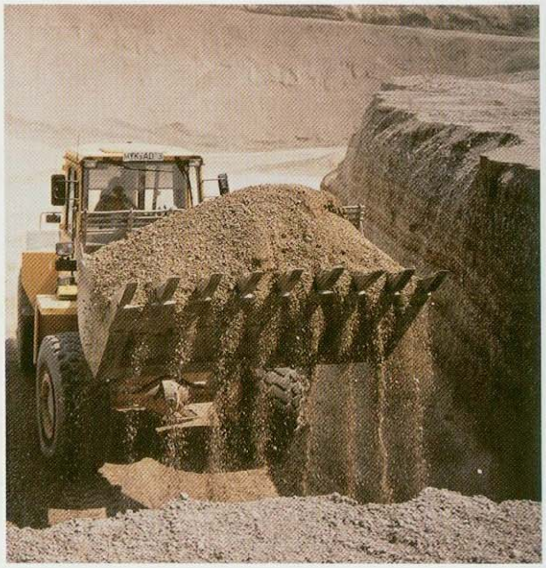
Pumice is an ideal construction material because it can be mined very easily and, mixed with cement, can be turned into building blocks without much ado. These blocks are not very strong and cannot be used for high-rises or television towers. On the other hand, they insulate very well because of the high porosity of the pumice particles. They are thus sold e.g. in Germany as insulating light-weight building blocks. A major pumice industry has developed in the basin of Neuwied, east of Laacher See in Germany. However, much of the pumice cover formed about 13 000 years ago has been mined (Fig. 15.14).

On Merapi, the unconsolidated pyroclastic block flow deposits are utilized almost immediately after an eruption to build protective dams (sabo dams) next to the valleys that channel the block and ash flows.

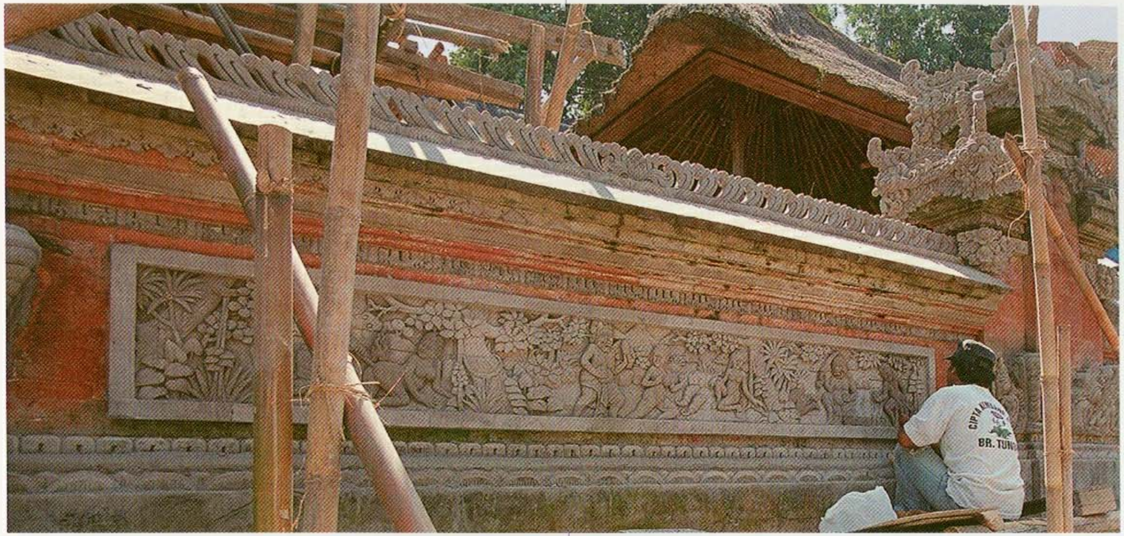
Lithified tephra, *tuff*, forms by different processes. In the Eifel in Germany, e.g., the originally unconsolidated deposits of pyroclastic flows, deposited warm but not extremely hot became zeolitized with age, specifically their pores became filled by secondary minerals (zeolites), where soaked by groundwater. These rocks are still mined today and can be found throughout the country, for example in railway stations in Frankfurt, Hamburg and many other large cities.

Ignimbrite deposits have been used to advantage in many early cultures all over the world in places where caves could be dug easily without the

▼ Fig. 15.13. Nephelinitic lava flow Hohenfels near Gerolstein (Eifel, Germany), a basalt popular with sculptors



► ▼ Fig. 15.14. Pumice mining at Nickenich (Laacher See area)



◀ Fig. 15.15. Bas relief at the wall of Hindu Temple under construction. The material is a poorly welded ignimbrite erupted from Batur Caldera (Bali). The ignimbrite is the main rock on which the famous stone sculpture industry on the island is based

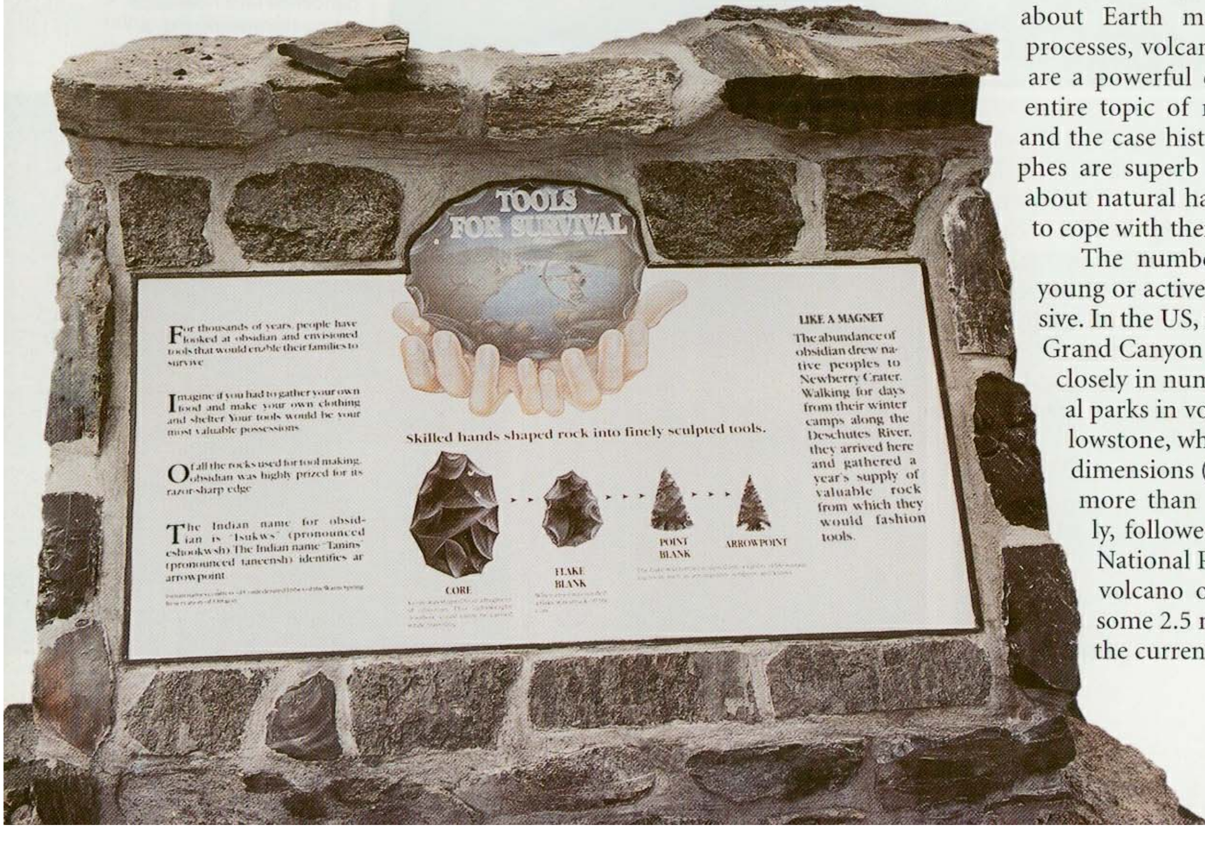
◀ Fig. 15.16. Sculptures of "little gods" (Ojizosan) made of andesite lava. Such figures, many hundreds of years old, are common along roadsides in Japan. They are worshipped down to the present day. Omuroyama volcano (Izu Peninsula, Japan)

▼ Fig. 15.17. Slabs of surface layers of prehistoric pahoehoe lava flow decorating the entrance to a house. Restinga (El Hierro, Canary Islands)

walls collapsing. Caves at Göreme (Turkey), those carved by the Etruscans in Central Italy, or those dug by Indians in New Mexico are well-known examples. Moreover, welded ignimbrites that can be cut into blocks are used in many countries as building material. These often orange or reddish flamed rocks can be seen easily in many public and private houses in South America, Central America, on the Azores, Canaries, Italy, Armenia and many other countries. Volcanic rocks of many types have been a favorite raw material for sculptors over the centuries (Figs. 15.15, 15.16). Sometimes nature has already done the job by creating most attractive ornamental material, wrinkled surface slabs of fluid basalt lava being especially popular (Fig. 15.17).

The production of *cement* is a major economic problem in many developing countries because there is either not enough limestone in

▲ Fig. 15.18. Pieces of obsidian on the surface of a rhyolitic lava flow (Newberry crater, Oregon, USA). Obsidian was a popular raw material in many ancient and pre-historic cultures for a variety of tool and ornamental purposes. Even today obsidian is used as jewelry, for example in Mexico and Georgia



▼ Fig. 15.19. Illustration in Newberry Park of how Indians used obsidian from rhyolite lava flow (Oregon). See also Figs. 4.4, 9.12, 9.13

the country or the costs for buying oil for heating the furnaces to make cement are exorbitant. Zeolitized tuffs, when crushed, make an excellent cement with hydraulic potential under water. These cements have been used for building dikes in Holland or for the lower foundation of bridges across rivers. Such material is mined in many countries, such as Turkey and Indonesia.

Pavement made of fine-grained *blue basalt* has been popular in former times in many countries in Europe. The use of basalt has seen a recent renaissance e.g. in the restoration of churches, such as the Cologne Cathedral, because it is much less affected by noxious environmental gases, such as SO_2, than sandstone.

Obsidian is perhaps the best-known volcanic raw material used in many ancient cultures from Asia (Armenia) through the Mediterranean area to Latin America (Figs. 15.18, 15.19). The reason is that the glass is very homogeneous and commonly does not contain any phenocrysts. Thus, obsidian breaks with extremely sharp edges and can be used for many purposes, for example for cutting material, or as arrowheads. In some countries, surgeons even prefer obsidian knives to those made of steel.

The Attraction of Volcanoes and Volcanic Landscapes

Large earthquakes often result in major human tragedies as well as destruction of vital infrastructures and countless buildings. Fractures in old buildings may tell us about past earthquakes (Fig. 15.20) but remnants of these destructive powers of nature are commonly quickly removed and covered by new buildings. Obviously, areas devastated by earthquakes are not favorite tourist spots. The popular museum and information center in Kobe (Japan) built to be a reminder of the particularly destructive Kobe 7.3 earthquake on 5 January 1995 is an exception.

Spectacular volcanic eruptions, in contrast, appeal to all senses: they can be seen, felt and even smelled. Some continue for days, weeks or even longer and many draw huge crowds of sightseers. No doubt: volcanoes, active ones, quiet ones and extinct ones, are major magnets to tourists (Figs. 15.21–15.24). When lecturing to school children, I found that volcanoes only compete with dinosaurs as the most attractive topic. In learning about Earth materials and deep Earth processes, volcanoes and volcanic deposits are a powerful educational tool. And the entire topic of natural hazard mitigation and the case histories of volcanic catastrophes are superb teaching material to talk about natural hazards in general and how to cope with them.

The number of visitors in areas of young or active volcanism can be impressive. In the US, for example, the bestsellers Grand Canyon and Yosemite are followed closely in numbers of visitors by national parks in volcanically active areas. Yellowstone, where geysers have American dimensions (Figs. 7.19, 15.5), leads with more than 3 million visitors annually, followed closely by the Hawaiian National Park, where the most active volcano on Earth, Kilauea, attracts some 2.5 million visitors a year. Even the currently inactive Mount Rainier,

◄ Fig. 15.20. Church, destroyed during a large earthquake in 1956 on the rim of Santorini caldera (Greece)

the largest volcano of the conterminous United States, is visited by some 2 million people annually. Mount St. Helens, which awakened dramatically on 18 May 1980 and remained active until 1986, has been declared a National Volcanic Monument under the jurisdiction of the Forestry Service. It attracts an increasing number of visitors, 1 million alone in 1997. Beautiful Crater Lake in Oregon (Fig. 9.45), the deepest lake in the US created by a huge eruption some 7 700 years ago, is another highly popular national park.

The easily accessible craters of active volcanoes Irazu and Poas (Fig. 12.27) in Costa Rica close to the capital of San Jose have been a must on tours in the country for decades. But even the relatively remote but more spectacularly active andesite volcano Arenal (Fig. 8.15) has developed into a major tourist attraction. The number of

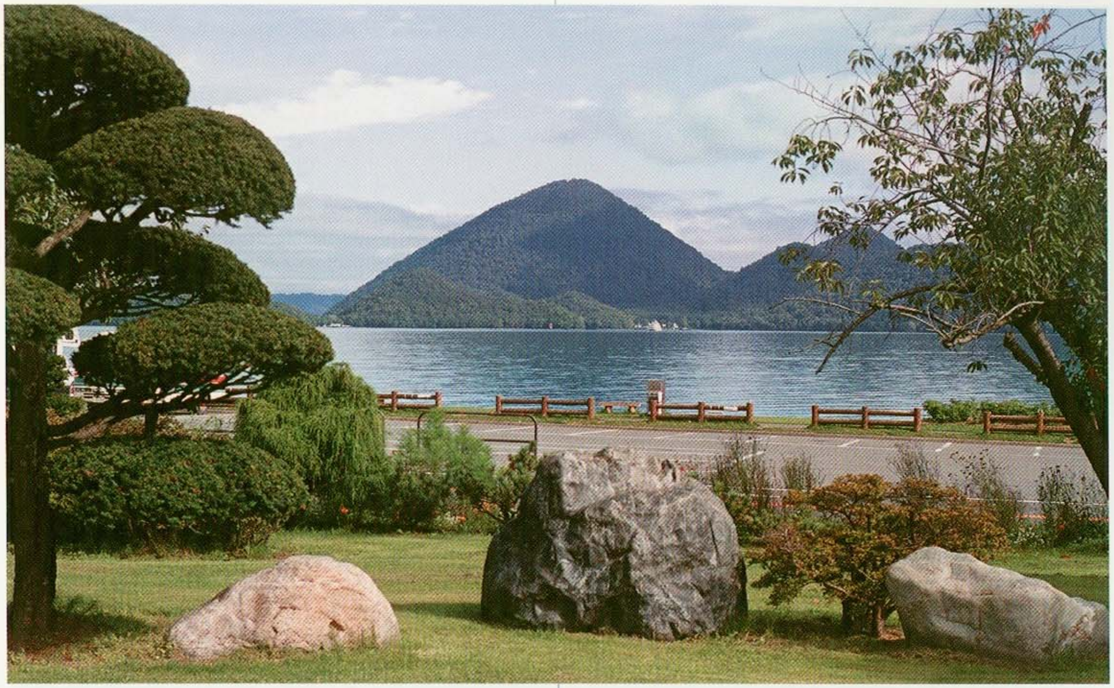
▼ Fig. 15. 21. Pico de Teide (3 718 m a.s.l.), viewed from the bottom of Las Cañadas Caldera (ca. 2 000 m a.s.l.). Front of a highly viscous phonolitic lava flow broken up into blocks in the middle ground. Tenerife (Canary Islands)

▲ Fig. 15.22. Volcanoes Toliman (*left*, 3 158 m a.s.l.) and San Pedo (*right*, 3 020 m a.s.l.) on the rim of Atitlán caldera (1 562 m a.s.l.) (Guatemala)

bungalows and hotels around the volcano is growing by the year. The hot avalanches generated on 9 May 1998 and even more recently have further added to the attraction of this volcano. Revenues from tourism have now outpaced those from agriculture in Costa Rica, volcano attraction representing a significant share. In neighboring Nicaragua, the easily accessible Masaya lava lake and crater complex (Fig. 4.24) and the frequently erupting Cerro Negro scoria cone (Fig. 7.7) are fast becoming standard places to visit. Indeed, volcano tourism may become a significant economic commodity in Nicaragua.

In Europe, the most famous young volcanic areas are located in Sicily. The gifts of nature include the largest and most active European volcano Etna, and, in the nearby Aeolian Islands, the prominently active volcano Stromboli and the island of Vulcano, home of the ancient mythical god Vulcanus. Vesuvius on mainland Italy opposite the Aeolian Islands, once very active but quiet since 1944, attracts a huge number of tourists, not the least because of the once-buried cities of Pompeii and Herculaneum, where new discoveries are made even today despite centuries of excavations. The unusually spectacular eruptions of Etna volcano in Sicily in 2001 and 2002 have resulted in a major increase in tourism, many people wanting to get a first-hand impression of Etna on fire. On the other hand, the sudden – and hopefully temporary – decline on December 26, 2002, of the famous intermittent eruptions of permanently active Stromboli that was almost continuously active for thousands of years, is a major blow to tourism in the Aeolian Islands. Even further north, in France and Germany, areas of young Quaternary and even Holocene volcanism are also drawcards for tourists. These volcano fields are also one of the cradles of volcanology, especially Central France, where milestone discoveries were made in the early part of the second half of the eighteenth century (Chap. 1).

Fire and ice are the central buzz words in the Icelandic tourism industry; this entirely volcanic land in the northern Atlantic attracts hundreds of thousands of tourists annually. Farther south, the Azores, Madeira and especially the Canary Islands with their spectacular volcanic scenery all owe much of their touristic appeal to their volcanic nature and activity.



◀ Fig. 15.23. Lake Toya, the most popular tourist area in Hokkaido (Japan). The dacitic domes have grown in the lake of Toya caldera

◀ Fig. 15.24. Tourist groups on the way to fumaroles in the crater area of Asahi-dake volcano (Daisetsu Mts., central Hokkaido, Japan). The crater area and the picturesque steam vents draw some 500 000 visitors annually

Craters have fascinated man for millenia, the early Greek philosopher Empedocles being said to have finished his live by jumping into one of the craters of Etna volcano, a dark side of volcano attraction that is still with us in some countries. In Europe, the craters of Stromboli, Etna, those of the logistically most easily accessible Vesuvius or Vulcano are prominent goals for people being moved by peering into the depth of the Earth. Bandama crater on Gran Canaria (Canary Islands) and of course Halemaumau on Kilauea volcano and the crater on active Oshima Island not far from Tokyo are examples in other parts of the world. Some craters such as Ngorongoro in east-

► Fig. 15.25. Famous painting by unknown artist picturing the explosive eruption of Asama Volcano in August 1783 (Honshu, Japan). Courtesy of Mr. Hiroo Misaizu

ern Africa or Mt. Suswa in Kenya are attractive not only for their wildlife but also the grandeur of the volcanic crater landscape.

Many lakes hosted in – or created by – volcanoes have few rivals in grandeur among lakes worldwide. Some of the most spectacular volcanic lakes have formed in calderas, maars or other types of craters. Examples include Crater Lake in Oregon (Fig. 9.45), Tianchi across the Chinese-Korean border (Fig. 9.51), Lake Atitlan in Guatemala (Fig. 15.22), lakes Ilopango and Coatepeque in El Salvador, Laguna de Apoyo in Nicaragua or the water-filled calderas and maars in Italy, France and Germany (Fig. 12.20). Caldera lakes are ubiquitous in Japan, the classic site being Hakone caldera close to Mt. Fuji. Caldera lakes abound in Hokkaido and include Lake Toya, the most popular tourist spot in Hokkaido (Fig. 15.23), bordered in the south by very active Usu volcano and, farther north, Akan, Kutcharo and Mashu caldera lakes. Examples on Honshu include lakes Towada and Ashino-ko. Other famous examples of caldera/crater-hosted lakes include Lake Toba in Sumatra, site of the world's largest Quaternary volcanic eruption, Lake Taal near Manila (Philippines) and lakes Taupo and Rotorua in New Zealand.

Lakes accumulated behind volcanically created dams – debris avalanches, lavas, and debris flows – have formed in many volcanic areas in the world. Lake Myvatn in northern Iceland is the classical example in Europe. The lake-dotted landscape south of very active Komagatake volcano in Hokkaido, where a major debris avalanche dammed up rivers and creeks in 1640, has developed into a major tourist attraction. Similarly, a basaltic lava flow spread from the flanks of Mt. Fuji in A. D. 864 caused the formation of several lakes in the Fujigoko, the five-lake area. The debris avalanches resulting from the spectacular collapse of the northern flank of Bandaisan dammed up Nagase river to create several lakes.

In many countries blessed with young volcanism, the most enjoyable benefit from – and direct impression of – volcanic heat are *hot springs.* The culture of hot springs is nowhere more developed than in Japan. Hot water pools can be found in many hotels throughout the country. Even more important for developing and maintaining social contacts are the public hot baths both outdoors and indoors, where neighborhood folks gather in the evening to relax from a hard days work and enjoy gossip. Bathing in hot springs is also part of the culture and a major tourist attraction in Iceland, Hungary (especially around Lake Balaton), Italy and other countries.

This chapter should not end without even a brief mention of the role volcanoes have played in the arts over the centuries. Rendition of the explosive energy and havoc brought about by destructive eruptions (Fig. 15.25) has been – and still is – one way to cope with disaster and to remind posterity of a past catastrophe. The 18th

◄ Fig. 15.26. Eruption of Vesuvius in 1774. Painting by Jakob Philipp Hackert. Staatliche Museen Kassel, Neue Galerie, Inv. No. 1875/1629 (with permission)

century was a particularly rich period in which highly active Vesuvius came to fame in the works of many artists from several countries, some having made their home in Naples at the foot of the spectacular volcano (Fig. 15.26). It was the light effects and spectacular illuminations of lava fountains or lava flows especially at night that attracted the painters but also the beginning of men's curiosity in finding out about the nature of volcanoes. In fact, Hackert, the artist of Fig. 15.26, was cooperating with the great William Hamilton, father of modern scientific inquiry into the workings of volcanoes (Chap. 1). In Japan, on the other side of the globe, Hokusais Thirtysix Views of Mt. Fuji – or the later One Hundred Views of Fuji – embody the deep feeling of the Japanese people for this towering cone for more than 1 000 years (Fig. 15.27). Mt. Fuji has been the symbol for Japan and for volcanic cones par excellence not the least through the famous woodcuts of Hokusai. It matters little that the most elegant curve of the cone of the volcano that conveys an immortal sense of beauty, is rather accentuated by the artist. In reality, the slopes of the upper part of the cone are straight (Fig. 8.12). But then Hokusai was not a scientist. And his rendition of the esthetic grandeur of Mt. Fuji has become a far more powerful symbol of the beauty of nature than any scientific paper can ever achieve.

Summary

The benefits of volcanoes have lured people to settle nearby in many parts of the world. Foremost is the importance of the fertile volcanic soils, such as in Latin America, the southwestern Pacific (Philippines, Indonesia) and Japan, but also in the young volcanic areas in Africa or the Canary Islands. This fertility is based on three properties, provided the climate is warm and wet: the ability to hold huge amounts of water on hydrated glass and secondary mineral phases, and to release it slowly; the supply of some essential plant growth elements (e.g., K, Mg, Se); and the glassy, unstable structure of the particles, which quickly release important elements, and which are rapidly transferred into crystalline and short-range-order clay minerals.

The high temperatures beneath young volcanoes, caused by underlying magma reservoirs, are used by man directly and indirectly. Geothermal energy sources are very important in some coun-

▶ Fig. 15.27. Four weather levels from fair weather with blue sky at the top to thundershowers at the foot of towering Mt. Fuji. Famous woodcut # 42 by Hokusai from "Thirty-six Views of Fuji" actually represented by 46 woodcuts

tries, such as New Zealand, Iceland or Italy, providing a major fraction of the energy supply.

Volcanic rocks have been used for tens of thousands of years as aggregates and tools because they show many advantages compared to other rock types. They are generally easy to mine. Obsidian is the perfect raw material for sharp knives, arrow points and other tools. Massive lapilli deposits or ignimbrites are splendid raw materials for lightweight and highly insulating building material because of their high porosity and soft nature.

Young volcanic landscapes provide for some of the most beautiful scenery on Earth. They represent tourist attractions of the first order because of their morphological variety, including crater lakes, geysers, and hot springs – or because volcanoes are still active or show signs of recent activity.

Volcanoes have attracted man not only for their obvious economic benefit, their soils, raw materials, the hot springs. The awe-inspiring grandeur of active and dormant volcanic edifices symbolize the power of the deep Earth like no other mountains. Quite naturally, volcanoes have played a major cultural and religious role over the millennia in many parts of the world. They have been, and commonly still are, viewed as the site of gods or demons, even in highly industrialized and secularized societies such as Japan (Fig. 1.1).