The Active Lava Flows of Kilauea Volcano, Hawaii

Hetu Sheth

Hetu Sheth is at Department of Earth Sciences, IIT, Mumbai. He is interested in modern and ancient volcanoes and what they mean for the composition and dynamics of the Earth's interior. He enjoys instrumental music, reading and Nature.

Kilauea volcano in the Hawaiian Islands, Pacific Ocean, is the world's most active volcano. Observations of active lava flows of Kilauea have a great relevance to studies of older, extinct volcanic systems, such as those found in India.

The Fundamental Stuff: Magma and Lava

Our planet Earth is very hot inside, and it gets rid of its internal heat by means of volcanoes. We are all familiar with the name *lava*, which is a molten rock that comes out of volcanoes, it cools, and solidifies into a new rock. When lava is below the Earth's surface, it is called *magma*. Why and how does magma form? By melting of pre-existing solid rocks. Many mechanisms can lead to the melting of the Earth's interior. For example, melting can occur as a result of a sufficient increase in temperature due to the radioactive decay of isotopes of potassium (K), uranium (U), and thorium (Th). These elements exist in all rocks in variable amounts. Once magma forms, it separates from the remaining source rock and rises towards the surface. During this time, many processes act on it. It may assimilate solid rocks in its way and change its chemical composition. Also, crystals may form in the magma, and they may be left behind, or brought up to the surface.

By definition, magma cannot be directly observed or collected, so a lava flow erupted on the Earth's surface is obviously the next best thing. The chemical composition of a lava flow erupted from a volcano gives valuable information on (i) the nature of the source rocks that melted, (ii) the processes that led to melting, and (iii) the processes that modified the composition of the original magma. Rocks which form by the solidification of magmas or lavas are known as 'igneous' rocks, and the study of such rocks is known as 'igneous petrology' (from the Latin *ignis* = fire, and Greek *petros* = rock, *logia* = discourse).

Keywords
Volcano, lava, magma, Hawaii.

Why Study Volcanoes?

Besides the great academic interest in volcanoes and their products, scientists observe and study volcanic eruptions for more practical reasons as well. Volcanoes are often very destructive to life and property, and entire cities or civilizations can be wiped out during major volcanic eruptions. It was the cataclysmic eruption of the Italian volcano Vesuvius in the year 79 AD that brought about total destruction of the cities of Pompeii and Herculaneum and the loss of 16,000 lives. Today, the city of Naples with a much larger population stands under the still-active Vesuvius. Many other cities with populations of tens of millions are situated right under dangerous, active volcanoes. One example is Mexico City, the capital of Mexico. Mexico City has over 20 million people living only 60 km from the 17,883-foot-high active volcano Popocatépetl. A name from the Nahuatl language of the Aztecs, Popocatépetl means 'smoking mountain'. 60 km is an insignificant distance to cover for a powerful blast of hot ash from such a major volcano, given that such ash flows are capable of velocities of $\geq$ 500 km/hour and temperatures of 400°C.

'Lahars', or volcanic mudflows, pose grave danger. The word 'lahar' is from Indonesia, a country with some of the most active and destructive volcanoes, but lahars occur worldwide. In 1985, a disaster occurred in Colombia, South America. An eruption in the crater of the volcano Nevado del Ruiz led to the melting of the glaciers on the summit, and this meltwater mixed with loose rock debris on the volcano's slopes, forming lahars. With little warning, these lahars swept down the volcano's flanks, moving 70 km in two hours and burying entire villages. 25,000 people died. The disaster could have been prevented, or at least greatly reduced in its scale, had the volcano been monitored. The science of 'volcanology' involves studying the locations, mechanisms, characteristics, and time scales of ongoing and past volcanic eruptions, and making useful predictions about potential future eruptions. Admittedly, you cannot prevent the volcanoes from erupting, but thousands of lives can be saved by mass migration of people to areas outside the danger zone well in time. Thus, volcanology and igneous petrology are not only of academic interest but also of enormous practical importance.

Types of Volcanoes

Volcanoes worldwide are very variable in their sizes, shapes, erupted materials, and internal structures. So there are many ways to classify volcanoes. An obvious one is the division into active, dormant and extinct volcanoes. Active volcanoes are those currently erupting, or those that have erupted within the last century or so. Dormant volcanoes are those not active today, but they may only be 'sleeping' and may erupt in the future. A major volcano with a life-span of a million years can well be asleep for tens of thousands of years between successive eruptions. Extinct volcanoes have been dead for such a long time that they are not likely to erupt again. India has only one active volcano today, that of Barren Island in the Andamans, far from India's land boundaries. However, a large volume of rocks making up the Indian subcontinent is of igneous, or volcanic, origin. A large part of western and central India is covered by lava flows (*Figure* 1). These lava flows were erupted about 65-60 million years ago in a stupendous volcanic episode known all over the world as Deccan Trap volcanism. However, most of these Indian volcanoes were not 'classic' conical volcanoes. Most people imagine a nice symmetrical cone when they hear of a volcano, and indeed many classic volcanoes such as Mt. Fuji in Japan are of this shape. The Deccan lavas were erupted instead from long, regional fissures or cracks in the earth's crust. Though long over, this great volcanic episode is thought by many researchers, including myself, to have played an important role in the extinctions of the dinosaurs and many other lifeforms existing then.

Active Volcanism in Hawaii

Observations of active volcanism are invaluable to geologists, as these allow meaningful interpretations to be made of now-

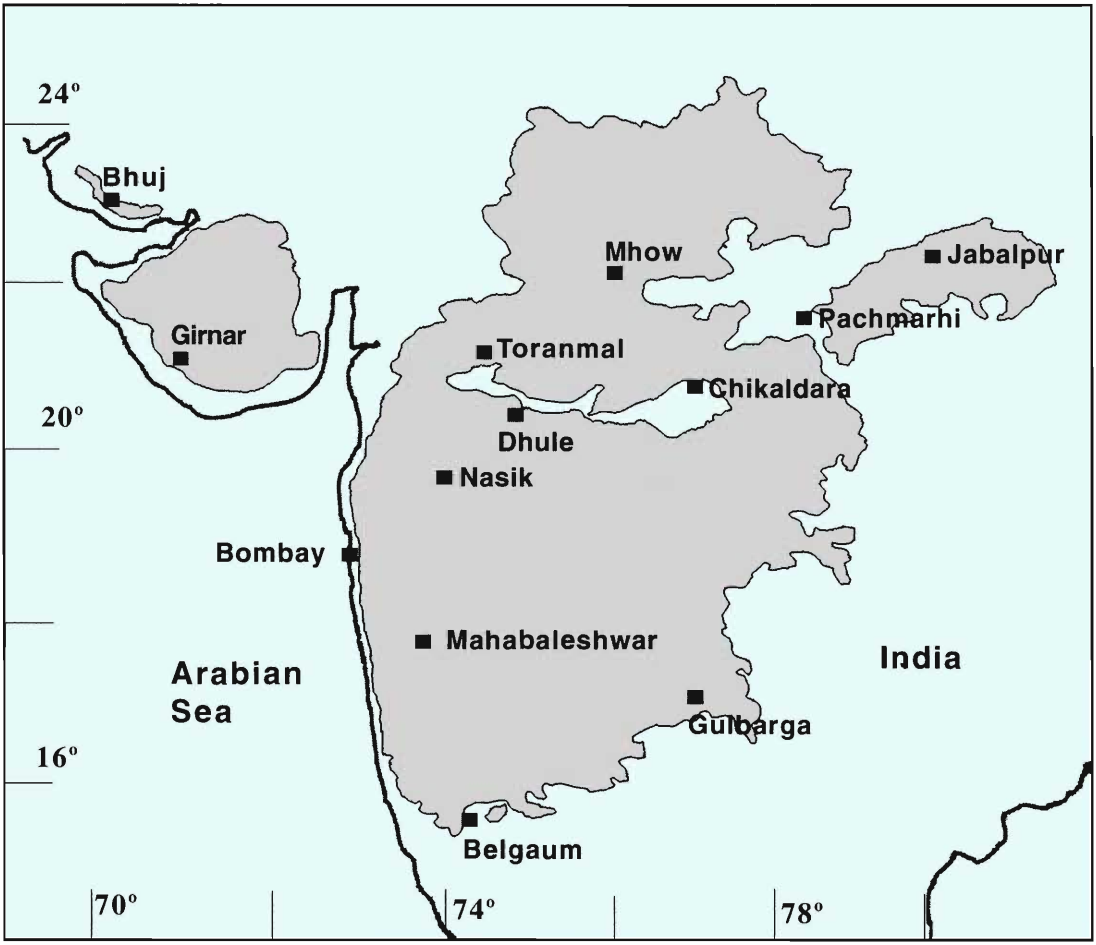

Figure 1. Map of the Indian subcontinent showing the enormous area (grey) covered by lava flows of the Deccan Trap volcanic episode, and some well-known localities.

extinct volcanic systems. Active volcanoes are therefore exciting places. Active volcanoes of the islands of Hawaii in the Pacific Ocean have been very important to the development of volcanology and igneous petrology. These islands are merely the exposed tops of huge volcanoes which rise about 10 km from the ocean floor. Most of them are extinct, but a large one by the name Haleakala (Hale-akala) is Earth's largest dormant volcano. In the vowel-rich Hawaiian language, Haleakala means 'house of the Sun'. Haleakala rises a massive 3055 m above sea level alone. There are three active volcanoes in Hawaii. One of these, called Loihi, is growing up from the ocean floor, and is yet thousands of feet below sea level. It can only be approached with a submersible. The other two active volcanoes are the world-famous Kilauea and Mauna Loa volcanoes. In Hawaiian, *mauna* means mountain and *loa* long. Mauna Loa has a height of 4166 m above sea level, and when measured from its base, is the largest volcano on Earth. It last erupted in 1984, and therefore is certainly in the active category. Kilauea is much smaller, rising 1248m above sea level, but is growing fast and steadily. Hawaiian legends say thatan angry, vengeful fire goddess Pele lives on Kilauea and shows herself to lonely travellers either as a beautiful young woman or an ugly old woman. It is to Pele that the Hawaiians owe their very land.

Kilauea, the Volcano that is Presently Erupting

Kilauea is the most active, most accessible, most safe, and best-studied volcano on Earth. Compared to volcanoes like Vesuvius, Kilauea is a very quiet volcano which almost always emits fluid lava and has rarely had explosive ash eruptions. It has had thousands of eruptions since it began forming, but its latest eruption began in 1983, and over 2 km^3 of lava have come out of its depths since then. This much lava would fill an imaginary cube with sides of 1.25 km. The eruption has gone on for years without showing any signs of stopping, and is going on as I write this. This is good news for the volcanologists, tourists, and tourist-dependent businesses such as airlines, rental car companies, and hotels. Tourists are often attracted to Kilauea by the abundant photographs of its magnificent 'fire fountains' reaching 500 m in height. Such major fountaining is in fact very rare and happens once in several years or decades, so most visitors are unlikely to see it.

The present site of the eruptions on Kilauea is a cone known as Pu'u' O'o' (In Hawaiian *Pu'u'* means hill, and *O'o'* is a native Hawaiian bird). The name refers to the resemblance of the cone to this bird's nest. After erupting from the crater at the top of the cone, the lava flows downslope and towards the ocean, just as normal rivers (of water) would do. The lava mixing with sea water immediately quenches and shatters, and makes new land.

It is extremely dangerous to be within about 0.25 km or so of the ocean entry area, because the warm rocky bench forming the edge of the island is unstable and can slide into the ocean with little warning. People have been killed by getting too close to the ocean entry. The sea water makes a huge steam plume due to the heat from the lava (which is at 1150 to 1200°C temperature) (*Figure* 2). Sulphur dioxide (SO_2) and other poisonous gases contained in the lava mix with the water, forming sulphuric acid and other harmful chemicals.

Figure 2. The ocean entry of Kilauea lava. Streams of yellow-hot lava are seen in the lower right distance, about 500 feet away. Note the huge steam plume, and the ocean in the background. March 2002.

It is even more interesting to watch what lava does on its way, well before it enters the ocean. Some of the lava, after coming out of the vent, moves in open channels, where it is exposed to the atmosphere. It therefore quickly loses heat and becomes highly viscous, rough, spiny, clinkery, and sharp. Such lava is known by the Hawaiian name *a'a'* (pronounced a-a). Someone has said jocularly that the name is appropriate, being the exact sound anyone walking bare-foot on such lava would emit. Open lava channels can also develop solid roofs by cooling, and the remaining lava moves underground in what is called a 'lava tube'. Lava flowing in a tube is not visible, except through openings in the solid roof of the tube. Such openings are known as 'skylights'. Equally spectacular and much more common are the 'breakouts' from the roofs of lava tubes, which bring some lava out on the surface (*Figure* 3). Breakouts happen as the lava is progressing internally toward the ocean, underground, and these breakouts continually increase the vertical thickness of the whole lava flow.

Figure 3. Lava emerges through the roof of an underlying lava tube, and flows into a pit. Each lava 'spring' is about a foot wide. Note how convex-outward 'ropes are forming in the one to the right. July 2002.

Viewing Breakouts

In general, it takes a hardy hike lasting a couple of hours over rough, solidified lava to get to the ocean entry area or the active breakouts on the way. On the way there is neither a drop of water nor any vegetation cover available. However, it is often possible to get to within 10 feet or so from the active breakouts, with excellent viewing conditions and photo opportunities. The heat of the lava can be felt at distances of up to hundreds of feet from the active flow front, depending on the wind conditions, getting you ready to witness Creation by Pele. Heat waves are also felt in the air. When you get within a few feet of a cooling and solidifying, partly molten lava lobe, you hear a crackling sound. Approach cautiously, for in some cases the ground under your feet could cave in, taking you with it. I have heard about people who were severely burned in this way.

Lava makes very beautiful, often surreal shapes, as it moves and solidifies. Structures preserved in solidified lava indicate the nature of flow (turbulent or laminar), which depends on the viscosity of the lava. Viscosity is a measure of the resistance to flow suffered by a liquid. Honey, which flows slowly and sluggishly, is much more viscous than liquids like water which flow rapidly and easily. Thus, viscosity is the opposite of fluidity. Lava flowing rapidly on steep slopes tends to break up and form viscous a'a'. Viscosity is inversely proportional to temperature, i.e., for a given chemical composition, the hotter the lava the less viscous it would be. Composition is very important, however. The richer a lava is in silica (SiO_2), the more viscous it is going to be. Highly siliceous lavas move very slowly and travel only small distances from the source. The typical lava composition produced in Hawaiian volcanoes is 'basalt', a rock which is relatively poor in SiO_2 (about 45-52 wt.% SiO_2) but is relatively rich in magnesium and iron. This composition, along with a high eruption temperature of 1150-1200°C, imparts a high degree of fluidity to the lava, such that it can flow at relatively high velocities of up to several feet per second (as in *Figure* 3). Watching active breakouts of such lava only a few feet away is an unforgettable experience, especially if you happen to be a geologist. The best shows are at night, when fresh lava breakouts glow bright yellow. Cloudy days are also good enough, when the lava shows shades of yellow to orange immediately as it comes out of a crack in the ground above a lava tube, and turns dull orange and then red and finally dark gray as it solidifies (*Figure* 3). For small lobes which cool quickly, this colour change takes only a few tens of seconds.

Ropy Structures and Pahoehoe

'Ropy' structures are very characteristic of the upper surfaces of individual lobes of the more fluid basalt lavas in Hawaii. The forms on these surfaces resemble cords, or ropes, and the appearance is similar to the wrinkled surface of an elephant's trunk. The Hawaiian word for this type of lava is *pahoehoe* (pa-ho-e-ho-e). Ropy structure is not found in a'a' flows. *Figure* 3 beautifully depicts the development of ropy structure, which begins to form at the front of a newly emplaced pahoehoe lobe as it comes to rest. The frontal part stops moving, but as new lava is being supplied at the rear end of the lobe, it crumples the cooler visco-elastic skin of the lobe into folds. Besides, these ropes get pulled outward by the lava moving beneath, but because the velocity of the lava is maximum along the central part of an elongated lobe, and least along its margins, the ropes on the skin become convex outward. If eventually the lava cannot be held by the lobe whose frontal part is chilled and at rest, the lobe bursts, and new lobes form (*Figures* 4 and 5). Thus lobes develop laterally, and pile up above each other, and the lava flow as a whole enlarges its length, width and thickness.

For old lavas, convex ropes preserved in pahoehoe lobes are a useful flow direction indicator (*Figure* 6), but it is hazardous to extrapolate from a single exposed lobe to the entire lava flow. In a single pahoehoe lava flow there can be thousands of individual lobes, and these can have their individual flow directions at any angle (even 180°) to the direction of progression of the lava flow as a whole. Thus the lava flow direction inferred from an individual lobe is always purely local.

If lava is continually being supplied to a lobe though slowly, the outer cooled crust slowly lifts up, the lobes swell over hours to

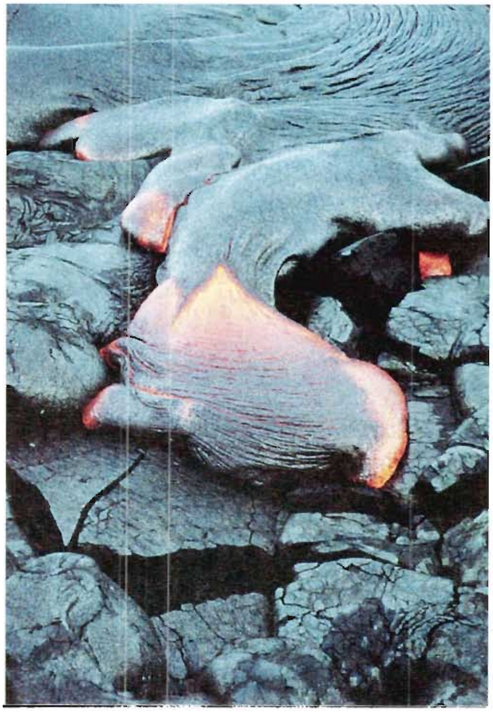

Figure 4. A fresh, ~3-feet-wide pahoehoe lava lobe that is only a few seconds old. Note how the colour of the lava progressively changes along the lobe's length. The front has come to rest and cooled sufficiently to look dark grey, while completely liquid lava (yellow to orange) is following at the rear. Ropes have begun to develop in the frontal part and will be propagated to the rear portions of the lobe. Note also the yellow lava oozing out of the sides of this lobe, to both right and left. The lobe swelled for a while before bursting along the sides. New lobes will have formed in less than a minute. (May 2002.) This is how many of the huge Deccan Trap lava flows of India may have been emplaced – nice and slow.

days, and may coalesce into larger units. This is known as 'inflation'. Old inflated lava lobes can be recognized through their characteristic internal structure, which consists of an upper and a lower crust separated by a thicker core zone, and the arrangement of vesicles (holes left by escaping gases). Vesicles are seen arranged both as vertical cylinders, which form as dissolved gases in the liquid rise upward due to their buoyancy, and as horizontal rows, formed as the rising gases encounter the overlying cold crust and turn horizontally under this mechanical barrier.

While breakouts are happening, remember that a lot more lava is continuously flowing under the surface. Most large lava flows

Figure 5. Another just-emplaced pahoehoe lava lobe only 5 feet away, flowing toward the right, with ropy structure developing nicely. Note the newer, small breakout lobe emerging from the base of this lobe towards me. (May 2002.)

Figure 6. Ropy structure preserved on the top surface of a pahoehoe lobe that is part of an older Kilauea lava flow. Foot-long rock hammer is for scale.

are able to spread far and wide not by surface flow, but by flow in a network of large tubes underneath a cooled crust. This enables the lava to lose very little heat as it travels away from the vent. Some long lava flows in the western USA. are known to have lost so little heat during transport that they covered distances of several hundred km from their eruptive vent before solidifying. It has been calculated that the drop in temperature suffered by these lavas was less than 0.5°C/km. This means that, lava with a temperature of 1200°C at the vent would still have a temperature of 1150°C after flowing 100 km from the vent and be completely liquid. This shows how thermally efficient lava tubes can be.

Interestingly, the old Deccan Trap lava flows of the Western Ghats are very similar in chemical composition to the modern Hawaiian lava flows. Many Deccan flows also have a morphology and internal structures (e.g., ropy structures) very like those of the Hawaiian lavas. This means that observations of modern Hawaiian lava flows can be usefully applied in understanding the eruption mechanisms of the much older Deccan lava flows. Lava tubes do exist in the Deccan province. Despite considerable advances made in the chemical characterization of the Deccan Trap lava flows, systematic morphological studies of these huge lava flows have barely begun yet. Exciting results lie ahead for geologists pursuing research on India's old volcanic geology, which shares so many features with active volcanic areas such as Hawaii and Iceland. It is with such comparative studies that we can hope for an understanding, not only of *why* and *when* it happened here in India, but also *how*.

Suggested Reading

[1] R Decker and B Decker, *Volcanoes in America's National Parks*, Odyssey Publications, p. 256, 2001.

[2] J Tenbruggencate, *Hawaii: Land of Volcanoes*, Mutual Publishing, p. 102, 2001.

[3] J-M Bardintzeff and A McBirney, *Volcanology, 2nd Edn.*, Jones & Bartlett Publishers, Sudbury, MA, USA, p. 268 , 2001.

[4] H Sigurdsson, *Melting the Earth: The History of Ideas on Volcanic Eruptions*, Oxford University Press, p. 260, 1999.

Address for Correspondence
Hetu Sheth
Assistant Professor
Department of Earth Sciences
Indian Institute of Technology
Mumbai 400 076, India