Part III

# Effusive Volcanism

**John Stix**
*Department of Earth & Planetary Sciences, McGill University, Montreal, Quebec, Canada*

This section of the Encyclopedia is concerned with volcanoes and volcanism dominated by comparatively quiet outpourings of lava in all its guises. This style of volcanic activity is found on both land and in the oceans, and the sizes of eruptions range from very small to very large. Although lava compositions are dominated by basalt, the most common volcanic rock on Earth, lavas do exhibit a large compositional range, with attendant differences in rheology hence eruptive behavior.

Chapter 17 describes the myriad types of aa and pahoehoe lavas which are produced by basaltic volcanoes. These are then contrasted with blocky lavas which are generated by magmas of more felsic composition. These lavas resemble aa in their overall structure but they are generally much thicker; nevertheless, large scale surface and internal folding can also be observed in felsic lava flows. The internal structure of aa lava is characterized by a brittle crust, adjacent visco-elastic layers, and a hot core zone. Lavas commonly undergo inflation where the front of the lava stalls while the interior of the lava fills with fluid lava. In terms of transport, lava is transported in open channels and in enclosed tube systems, both of which range from simple to complex distribution systems. As lava is transported downslope, it undergoes changes in its temperature and rheology. Cooling is enhanced in open channels compared to tubes. As the cooling progresses, the lava crystallizes and becomes stiffer rheologically.

Chapter 18 addresses the extrusion of highly viscous magma of more felsic composition. Lava domes are notable, as they are commonly associated with explosive activity, attesting to the complex interplay of processes which control effusive versus explosive behavior. Another remarkable aspect of lava domes is that sometimes they can grow very fast, within days to weeks; other times they can be slow-growing or even static. Many lava dome complexes show highly episodic behavior, with periods of fast and slow growth. A few lava domes can be active on timescales of tens of years. Similar to lava flows, domes have highly variable rheology including a deformable core and a carapace which is brittle generating significant talus. The chapter examines two historic lava dome eruptions that are probably the best studied in the world. Mt St Helens experienced a series of lava domes during two time periods in 1980−1986 and 2004−2008; the contrast between them is interesting, as the first period occurred after the May 18, 1980 Plinian eruption, while the 2004−2008 activity was characterized nearly exclusively by dome growth. Soufrière Hills volcano on the island of Montserrat began experiencing lava dome activity in 1995, and this activity continues to today. Soufrière Hills taught volcanologists much about lava domes, including the delicate transitions between effusive and explosive activity, and how eruptions can escalate during different time frames.

Chapter 19 discusses submarine lavas, highlighting the fact that these eruptions are dominated by basaltic eruptions, which due to their generally low volatile contents mean that the eruptions are either not explosive or only weakly so, usually in their initial phases. The lavas are characterized by pillow, lobate and sheet forms, which can be found together. Because these different lava flow morphologies are largely a function of effusion rate, their presence (or absence) can be profitably used to make such inferences. In some situations, basaltic lava can break. Commonly this happens when the lava is rapidly chilled by seawater, or when lava flows down steep slopes; the result is a fragmental glassy material termed hyaloclastite. In other situations, basaltic magma interacts with unconsolidated water-saturated sediments in the shallow subsurface; the product is peperite, a complex association of the quenched magma and the sediment. Submarine felsic lavas, while much less abundant than basaltic compositions, nevertheless produce some unusual features such as columnar joints of various sizes which can be used to infer the subaqueous environment. The combination of high magma viscosity and rapid quenching by water means that fragmented lava facies are both common and commonly associated with the coherent lava facies. Where sedimentation rates are high, synvolcanic intrusions may be present, particularly when the density of the felsic magma is higher than that of the water-saturated sediment.

Chapter 20 looks at glaciovolcanism in its myriad manifestations. Tuyas or mobergs are volcanoes produced beneath ice. Typically basaltic magma erupts into ice, melting it and creating a subsurface cavern. Eruptive products include pillow lavas and hyaloclastite, and these are typically found together. As pillows accumulate to form a subglacial edifice, slopes steepen, favoring the production of hyaloclastite, which is also enhanced by decreasing lithostatic pressures and greater degrees of expansion and explosivity. If the lava reaches the surface of the ice, a capping of coherent lava can form which protects the friable hyaloclastite facies beneath from erosion. Volcanoes of more felsic composition, such as andesitic arc volcanoes, can also have substantial volumes of ice resting on their edifices, so glaciovolcanism in these environments is significant. However, recognizing such products can be difficult, as the features are more subtle. Again, jointing patterns can be helpful to deducing their origin. Glaciovolcanism can be used for paleoclimate studies, including spatiotemporal distributions in a given area; under favorable circumstances, ice thicknesses can be estimated as well. The amount of heat transferred from magma during subglacial eruptions can be calculated and quantified. The chapter ends with an examination of three recent subglacial eruptions: Gjálp in 1996 and Eyjafjallajökull in 2010 (both in Iceland) and Redoubt in 2009 (Alaska, USA).

Chapter 21 explores volcanoes associated with mid-ocean ridges, the largest magma system on Earth. An important point to note is that most of the magma generated by mantle melting beneath mid-ocean ridges ends up as intrusive rock forming the new oceanic crust, with a relatively minor amount of magma erupting as lava. Shallow magma chambers appear to be common along fast-spreading mid-ocean ridges but much less common along slow-spreading ridges, attesting to the more discontinuous magma supply in these slower-spreading environments. Where imaged seismically, the tops of magma chambers at fast-spreading ridges also appear to be spatially focused and shallower than those at slow-spreading ridges. In terms of eruptive products, pillowed, lobate and sheet flows are observed, with a greater abundance of sheet flows along fast-spreading ridges and more pillow lavas along slow-spreading ridges. This difference may be ascribed to the different magma supply and effusion regimes.

Chapter 22 looks at the development of seamounts on the ocean floor. Seamounts form in a range of tectonic settings, including on or near mid-ocean ridges, within intraplate settings, and associated with subduction zones. Seamounts near mid-ocean ridges may develop from mantle processes similar to those responsible for magmatism at the ridge itself. Seamounts also result from plume—ridge interactions, and these seamounts tend to be larger in size. Seamounts have a variety of morphologies ranging from isolated cones through complex clusters to flat-topped structures, which are formed either by erosion at wave base or by lava infillings of summit calderas. Interestingly, since the seafloor is still not very well known or studied, we do not have an accurate estimate of the total number of seamounts; estimates for those with heights of at least 1 km range from 45,000 to 350,000, a range of nearly an order of magnitude. The model for seamount formation starts with an early stage followed by a shield-building stage, and terminating with more alkalic, smaller volume magmatism. These changes are generally correlated with mantle melting events, with the largest melting associated with the shield-building stage. Much of our knowledge regarding seamount and ocean island volcanism is based on the well-developed Hawaiian chain of islands and seamounts. Seamount lithologies include pillow lavas, volcaniclastic rocks, and intrusive rocks, such as dikes and sills, and many seamounts exhibit hydrothermal activity as well during and after the time they were magmatically active.

Chapter 23 focuses upon basaltic volcanic fields, which are quite common in a range of tectonic settings. These terrains are interesting due to their rather unusual characteristics. First, a field may comprise hundreds if not thousands of individual volcanic centers which are generally of basaltic composition. Second, the volcanoes are generally monogenetic, meaning that they erupt only once, then die. Third, the volume of an individual volcano is generally small and sometimes very small. Overall, the magmatic output from these fields can extend in time for up to a few million years and covers a large area. Despite this fact, individual volcanic centers within a given field commonly show vent clustering and vent alignments, attesting to control by the underlying structure including faults and the tectonic stress regime. Within such fields the character of the volcanism typically reflects both magmatic and phreatomagmatic styles of activity. Magmatic eruptions include scoria cones while phreatomagmatic activity is characterized by maars, tuff rings, and tuff cones. Statistics can be applied to estimate eruptive recurrence rates, while geochemistry can characterize magma source characteristics and magmatic processes, which can be quite diverse and variable. The main hazards from such eruptions are tephra falls, pyroclastic density currents, and lava flows.

Chapter 24 studies the remarkable magmatism and volcanism associated with flood basalts and large igneous provinces. Dwarfing volumes of currently active volcanoes by many orders of magnitude, these truly monumental eruptions are one type of supervolcano which have occurred repeatedly during the evolution of the earth (the other type of supervolcano are calderas, see Chapter 16). Large igneous provinces are found both on the continents and in ocean basins. The volume of individual eruptions may extend up to $10^3-10^4$ km$^3$, while the total volume of an individual province can range from $10^4$ to $10^6$ km$^3$. These are truly enormous numbers, and furthermore, the eruptions appear to occur over a very short time geologically speaking. For example, the output from a large igneous province may extend over only 1−3 million years, and it is possible that the bulk of this output may occur in an even shorter time frame. While flood basalts and large igneous provinces appear in some cases to be associated with divergent plate boundaries and mantle plumes, many large igneous provinces are surprisingly not well characterized in terms of their tectonic environment. Nevertheless, the occurrence of mantle plumes provides an attractive means to transport large volumes of material from regions deep in the mantle to the surface. Geochemical studies indicate that the sources of flood basalts have characteristics akin to mid-ocean ridge basalts and ocean island basalts, with a significant lithospheric component as well. Flood basalt eruptions are thought to occur through fissure systems, based upon smaller-scale examples and modeling studies.