SECTION 2: VOLCANISM (2 lectures)

2.1 Volcanic Rocks

There are various names that you will come across when reading about volcanism, either on this planet or others. Some of those used in this course are defined here. You are encouraged to learn a little more about the rocks and their mineral families in your own time to aid your understanding.

Lava - used here to mean molten rock that has been erupted.
Magma - fresh, molten rock, yet to be erupted or in the process of being erupted. It still has its original volatile content.
pyroclastic rocks - solid fragments ejected from a volcano.

Volcanic rocks are made of combinations of seven mineral families (with a few exceptions. These families are: olivines, pyroxenes, amphiboles, micas, feldspars, quartz and oxides. All but oxides are silicate minerals; oxides are mostly iron and titanium.

Within each family, the chemical composition may vary considerably within certain limits. You will see many names given to volcanic rocks depending upon their composition; they can be considered to vary in two ways - their silica content and alkali content.

Silicic (acidic)	rhyolite	light, quartz, feldspars	High SiO_2
	dacites		|
	andesites		|
			|
Basic (mafic)	basalt	dark, feldspars, pyroxenes	Low SiO_2

The alkali content is expressed in terms of its (Na_2O + K_2O) content. Within each group of basalt, andesite and rhyolite, there will be a variation in alkali content, most easily dealt with by calling them alkali basalts or alkali rhyolites, etc.

2.2 Magma and Lava

The viscosity of a fluid is an important parameter when considering volcanic processes. Viscosity may be defined as "the internal resistance to flow by a substance when a shear stress is applied".

The behaviour of different fluids with various viscosities are given specific terms.

FIGURE 2.1 (Stress vs. Strain)

Fluids such as water are described as Newtonian - the slightest stress will cause it to flow. It has a low viscosity.

Bingham fluids do not flow until a critical stress has been applied. This initial shear stress is termed its yield strength. Once moving, however, Bingham fluids flow at a rate directly proportional to the applied stress, like Newtonian substances. These generally have high viscosity.

Intermediate between Bingham and Newtonian are the pseudo-plastics which show a non-linear relationship between stress and strain, and have no definite yield strength. Most lavas behave in a pseudo-plastic way, although in simple terms they are often regarded as Binghams.

Several factors affect the viscosity of a fluid, including temperature, composition, volatile content and crystallinity.

FIGURE 2.2 (Effect of volatiles and temperature on viscosity)

Temperature has a rather dramatic effect on magmas, increasing its viscosity by up to several orders of magnitude for a decrease of several hundreds of degrees. All types of lava show this trend but the amount by which viscosity increases for a particular temperature drop depends on composition.

(Figure 2.2). This figure here shows the effect of composition well. Here you can see that silicic lavas (i.e. rhyolite) are always more viscous than basic ones at the same temperature.

To reduce the viscosity of a melt, its silicon-oxygen bonds must be broken. One effective way of doing this is by adding water which breaks the bonds by forming OH^- ions. Water will reduce the viscosity of both silicic and basic melts, but the effect is more dramatic in silicic ones.

The presence of solid crystals in the melt will tend to increase the viscosity of it, but the exact effect is difficult to quantify due to the variation in shape and size of the crystal.

What determines the thickness of a lava flow? The viscosity factor will naturally have some influence through the effect of the lava's yield strength.

FIGURE 2.3 (Thickness of a flow)

The thickness, t, a flow will attain before it will flow is given by:

$$t = \frac{\tau}{\rho g \tan \alpha} \qquad \text{(Eqn. 2.1)}$$

where τ = yield strength, ρ = density, α = slope and g = acceleration due to gravity. So, a more viscous lava will have a larger yield strength and hence greater thickness. The velocity of a flow is then given by:

$$v = \frac{\rho g t^2}{B\eta}\sin\alpha \qquad \text{(Eqn. 2.2)}$$

where B = constant (~3 for a flat surface) and η = viscosity. Here the more viscous lavas will travel slower than the less viscous ones.

How far a lava flow will travel is difficult to predict. With all else being equal, the effusion rate is one of the most important factors. In general, basaltic melts have far higher effusion rates than silicic ones and hence travel farther.

The lava flows made of basaltic material are likely to be the ones we refer to most when looking at bodies such as the Moon and others. Two forms of basaltic lava are familiar to geologists: a'a and pahoehoe. Both types of lava may be erupted from the same vent; chemically a'a and pahoehoe may be the same, it's just their physical structure that is different.

A common occurrence in basaltic lava flows are tunnels and tubes. These form when the surface of a flow crusts over whilst lava continues to flow underneath. When the source is cut off, the lava drains away downslope leaving behind an empty tube. Lava tubes allow a flow to reach much farther than on the surface by dramatically cutting down heat loss. Lava may flow ten times farther through a tunnel than by flowing on the surface.

2.3 Types of Eruption

There are various types of eruption ranging from effusive activity (passive emission of lava) to explosive activity, and everything in-between. On small scales, magma may erupt either effusively or explosively. On large scales, however, composition becomes important; large basaltic eruptions are almost exclusively effusive, large silicic eruptions almost exclusively explosive.

Flood lavas: the largest eruptions come from fissures and are known as flood lavas.

Wilson & Head give the mass eruption rate , M, as

$$M = wL\rho u_d \qquad \text{(Eqn. 2.3)}$$

where w = width of the fissure, L = length of the fissure, ρ = density of the magma and u_d = rise velocity of the magma. So, longer and wider fissures produce much higher eruption rates. These are typically basaltic in composition, low viscosity, high velocity flows. It is a common form of volcanism on other planets where flows extend for 100's of kilometres.

Hawaiian Activity: One of the mildest forms of eruption is that of Hawaiian activity. The islands of Hawaii are purely basaltic, erupted at high temperatures and low viscosities, travelling for some distance. It takes time to build a shield volcano with individual eruptions contributing only a small amount to the total volume of the volcano. Associated with both flood lavas and Hawaiian activity are fire fountains, where gases exsolving from the magma at lower pressures cause sprays of liquid lava to be jetted into the air.

Strombolian Activity: Also involves basaltic magma, but with a higher viscosity and yield strength than in Hawaiian activity. It is also more explosive, being characterised by intermittent bursts of activity throwing pyroclastic material 10's or 100's of metres into the air.

FIGURE 2.4 (Strombolian eruption)

The magma in a Strombolian eruption rises slowly in the vent, allowing bubbles to form and coalesce rising to the top of the magma column. The surface of the magma is eventually disrupted and pyroclasts are thrown out ballistically, and the whole cycle repeats with individual blasts separated by fractions of a second to hours.

Vulcanian Activity: A more explosive form of volcanism is known as Vulcanian. These eruptions are usually small (”1km^3) but material can be erupted to far greater heights than in Strombolian eruptions.

FIGURE 2.5 (Vulcanian eruption)

A higher viscosity magma is required for Vulcanian activity and andesitic magma is usually involved. Separate bursts of activity take place at intervals of minutes to hours. The ejected material is often found to be the remains of a shattered lava plug which formed in the vent.

The exsolution of gas from great depth cause a build up of pressure which eventually gets so great it breaks the overlying plug ejecting the fragments at high velocity (200-400ms^{-1}).

Plinian Eruptions: Another form of explosive volcanism, but relatively rare.

FIGURE 2.6 (Plinian eruptions)

They differ from previous examples in that their eruptions consist of sustained jets lasting for minutes or even hours. In Plinian eruptions exsolution may start at deep levels. Crucially, the bubbles do not rise through the magma, instead the magma and exsolved gas rise up at the same velocity. This can happen in high viscosity magmas (i.e. rhyolites) although basaltic plinian eruptions are not unknown. In these cases the magma would have to have a high velocity through the vent such that the bubbles did not have much time for relative movement.

Material is ejected at several hundred metres per second in plinian eruptions with huge amounts of material rising convectively in a column above the vent. Once the material in the column is finally deposited, the consequences can be devastating. Pompeii is an example of what can happen when a plinian eruption (in this case Vesuvius) occurs.

2.4 Volcanic Landforms

- Shield volcanoes FIGURE 2.7a
- Cones FIGURE 2.7b
- Composite volcanoes FIGURE 2.7c
- Domes FIGURE 2.7d

We've already seen that Hawaiian activity results in shield volcanoes. Shields are characterised by their convex form and very shallow slopes.

Cones are formed by more viscous magma and more explosive eruptions. Their form is convex with far steeper slopes than shield volcanoes, typically 30-40^{o}.

Composite volcanoes are cones with layering of lava flows and pyroclastic material, alternating through the structure.

As you move to even higher viscosity magma, volcanic domes are produced. These forms are generally not too large on the Earth, but are found to be much larger on planets such as Venus.

Reference List

Francis P., 1996, "Volcanoes - A Planetary Perspective", Oxford University Press

Wilson L., Head J.W., 1983, "A comparison of volcanic eruption processes on Earth, Moon, Mars, Io and Venus", Nature, 302, 663

Frankel C., 1996, "Volcanoes of the Solar System", Cambridge University Press