Some notes on igneous rock

by Vince Cronin, revised 23 September 2015

Principle of ***uniformitarianism***: The physical and chemical laws that govern the physical/chemical world are the same now as in the past. (That is, during virtually all of the 13.8 billion year history of the universe.)

Rocks are naturally occurring aggregates of mineral grains.

Igneous rock crystallizes from magma – a hot silicate melt.

Sedimentary rock develops as a result of sedimentation or precipitation at the ground surface

Metamorphic rock occurs when pre-existing rock (igneous, sedimentary or metamorphic) is changed by stress, pressure, or temperature changes.

Extrusive igneous rock crystallizes ***rapidly*** under relatively low pressure at or near Earth's surface. The texture of extrusive igneous rock features small crystals (<~1 mm), although in porphyritic rocks there might also be some larger crystals embedded in a groundmass of small crystals.

Intrusive igneous rock crystallizes ***slowly*** at relatively high pressure below Earth's surface. The texture of intrusive igneous rock features large visible crystals (>~1 mm).

A ***phaneritic*** igneous rock contains visible crystals that are typically >~1 mm in diameter, and are frequently ~1 cm in diameter.

An ***aphanitic*** igneous rock contains very small crystals that are typically <~1 mm in diameter.

Volcanic glass like *obsidian* is not a rock because it is not made (primarily) of mineral grains. It solidifies very rapidly over a few seconds to a few minutes – too fast for crystals to form.

A ***porphyritic*** texture in an igneous rock involves two distinctly different sizes of grains in the same rock. The general interpretation is that the larger grains formed over a relatively longer time in the magma chamber, and then a change in temperature/pressure caused the more rapid crystallization of the rest of the magma. That change is most easily understood in porphyritic extrusive rock, in which the larger ***phenocrysts*** probably grew while the magma was still in the magma chamber, and the smaller ***groundmass*** crystallized after eruption.

Different minerals crystallize at different temperatures and pressures. For example, the minerals *olivine* and *calcium-rich plagioclase feldspar* crystallize at higher (hotter) temperatures in the vicinity of 1200°C, while minerals like *potassium feldspar* and *quartz* crystallize at lower (cooler) temperatures in the vicinity of ~750°C. This relationship is illustrated in the classic Bowen's Reaction Series, although the BRS does not reflect the initial composition of all magmas.

Earth's crust is NOT floating on a sea of molten magma. Earth's lithospheric plates are NOT floating on a sea of molten magma. The only layer of Earth's interior that is in the liquid state is the outer core. Otherwise, magma exists in specific limited areas in the crust or uppermost mantle.

Magma can be found...

...above a subducting slab, approximately where the top of the slab reaches a depth of ~100 km,

...along a mid-ocean ridge or continental rift,

...above a hotspot, as occurs beneath the main island of Hawaii, under Yellowstone, and under Iceland,

...and associated with minor gaps in the crust caused by faulting, or in areas of unusually thick crust like the Himalaya.

Igneous rocks can be grouped into compositional twins: rocks that have different textures because they are intrusive or extrusive, but that have identical minerals.

- *granite* (phaneritic, intrusive) and *rhyolite* (aphanitic, extrusive) are felsic rocks
- *diorite* (phaneritic, intrusive) and *andesite* (aphanitic, extrusive) are intermediate rocks
- *gabbro* (phaneritic, intrusive) and *basalt* (aphanitic, extrusive) are mafic rocks

Magmas have different compositions because different processes can affect them. All magmas are produced by partial melting of pre-existing rock. Partial melting of the upper mantle produces a mafic magma that crystallizes to form *basalt* (aphanitic, extrusive) or *gabbro* (phaneritic, intrusive). Partial melting of the continental curst produces a more diverse array of magmas that tend to be more felsic. Some of the processes that further affect the composition of a given magma include:

- assimilation, in which bits of the rock that surrounds the magma chamber is melted or incorporated as chunks into the magma, which might result in development of xenoliths in the crystallized rock;
- mixing, in which magmas from two sources meet in a conduit or magma chamber and share some of their content;
- fractional crystallization, in which the minerals that crystallize at higher (hotter) temperatures form early in the crystallization process, stick to the walls or floor of the magma chamber, and deplete the remaining liquid magma of the elements that are now bonded into their crystal structures. So the magma becomes progressively enriched in elements that are not incorporated in the high-T minerals.
- different source areas, in which diverse source rocks are converted to magmas that have a diversity of compositions.

Intrusive igneous rock bodies

- dikes: cracks created by the injection of magma that cut across the pre-existing layering or fabric of a rock
- sills: cracks created by the injection of magma that are parallel to the pre-existing layering of a rock
- plutons: large round blobs of magma that rise through the crust, like the blobs in a lava lamp.

- stocks: an exposure of igneous rock at the ground surface that has an area less than 100 km^2
- batholiths: an exposure of igneous rock at the ground surface that has an area greater than 100 km^2; examples include the Sierra Nevada, Idaho, and Southern California batholiths
- laccoliths: a mushroom-shaped intrusive body with a generally planar-horizontal base and an arched top, developed because the magma pressure in a sill was sufficient to lift the rock above it.
- necks: the hard, erosionally-resistant interior conduit of an extinct volcano that is left behind as a high-point in the landscape after the rest of the volcano has eroded away.

Volcanoes, viscosity and magma. Mafic magma begins to crystallize at a higher (hotter) temperature than felsic magma. Mafic magma also has less silica (minerals with silicon + oxygen) than felsic magmas. The result is that mafic magmas are less viscous than felsic magmas, meaning that they flow more easily – they are more like water than like silly putty.

Magma viscosity is affected by several things. The viscosity of a magma tends to be ***greater*** if it has…

…less thermal energy (lower temperature)

…more silica

…less water

…fewer gas bubbles

Low-viscosity (mafic) magmas tend to produce volcanoes with ***gently sloping sides*** and ***broad bases***, like the volcanoes of the Hawaiian Islands. The main island of Hawaii is the tallest mountain on Earth if measured from its base (below sea level) to its top, and it is broad enough to cover the state of Wisconsin. These ***shield volcanoes*** do *not* produce explosive eruptions, although they can appear to be very energetic on the human scale for anyone standing close to an active vent during an eruption.

High-viscosity (felsic) magmas produce volcanoes with more ***steeply sloping sides*** and ***narrower bases***, like the volcanoes of the Cascade Range of northern California through British Columbia, or the Andes Mountains of South America. These ***stratavolcanoes*** (or ***composite volcanoes***) can produce violent explosive eruptions, such as the eruptions of Mt. Vesuvius in Italy (79 AD), Mt. St. Helens in Washington (1980), and Mt. Pinatubo in the Philippines (1991).