

Science Education Collection

Intrusive Igneous Rocks

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Overview

Source: Laboratory of Alan Lester - University of Colorado Boulder

Igneous rocks are products of the cooling and crystallization of high temperature liquid rock, called magma. Magmatic temperatures typically range from approximately 800 °C to 1,200 °C. Molten rock is, perhaps luckily for humans, an anomaly on planet Earth. If a random and imaginary drill hole were made in the Earth, it would most likely not reach a region of truly and totally molten material until the outer core, at nearly 2,900 km beneath the surface (Earth's radius is 6,370 km). Even there, this molten material would predominantly consist of liquid iron, not true silicate rock, and be incapable of ever reaching Earth's surface.

Volcanic eruptions and igneous rocks do occur though, and they are evidence that there are indeed isolated regions of melting and magma generation within the Earth.

Principles

There are three primary mechanisms for rock melting within the Earth:

1) Addition of heat

Melting can occur when rocks in the Earth's mantle or crust experience an increase in ambient temperature. This is a result of high temperature magma coming into contact with rocks that have a lower melting temperature.

2) Addition of volatiles

Melting occurs in the Earth's mantle when volatile components (generally H₂O, but other components, such as CO₂, are possible) diffuse into a zone of rocks that are near but not quite at their melting temperature. This is called flux melting and is analogous to a welder using a flux to lower the temperature of melting for the metals that they are working with. This is the primary mechanism for melting above a down-going slab at a subduction zone, where volatiles escaping from the subducting oceanic lithosphere enter the overlying mantle and bring about flux melting. Above subduction zones, we often see a chain of volcanoes, e.g. the Cascade and Andes mountains.

3) Decompression

Melting occurs in the Earth's mantle when the plastic and mobile asthenospheric mantle rises and undergoes decompression. This rising mantle experiences relatively minimal heat loss (as rocks are poor conductors of heat), and since melting is pressure dependent, the loss of pressure can cause the rising asthenospheric mantle to melt.

Cooling and Crystallization of Magma

Magmatic cooling and crystallization can occur in a variety of environments. However, we distinguish between the two key circumstances of surface (rapid) cooling and Earth interior (slow) cooling. These generate rocks with different crystal size, shape, and arrangement - the combination of factors that geologists refer to as texture. Surface (rapid) cooling generates rocks that are collectively called extrusive. Extrusive igneous rocks are characterized by very small crystals (invisible to the naked eye), a kind of texture referred to as aphanitic.

In contrast, cooling that takes place as a result of magma bodies solidifying in the Earth's interior (*i.e.* subsurface cooling) is much slower, and this leads to rocks with relatively large crystals, visible to the naked eye, and are collectively called intrusive igneous rocks. The coarser and larger grain sizes generate a texture referred to as phaneritic (**Figure 1**).

Composition of Magma

Ultimately, as described above, igneous rocks are classified on the basis of two features - texture (which is generally a consequence of the environment of cooling, *i.e.* surface or subsurface) and their composition. Compositionally, igneous rocks span a range of felsic to intermediate to mafic. Felsic rocks are rich in aluminum and silica (silicon and oxygen), whereas mafic refers to rocks that contain less silica and more iron and magnesium. Magmas compositions can range the entire spectrum between felsic and mafic. Those that are neither highly felsic nor highly mafic are referred to as intermediate. In a quantitative sense, felsic rocks contain approximately 60-75% (by weight) SiO₂, and are broadly called granitic. Mafic rocks contain approximately 45-60% (by weight) SiO₂, and are broadly basaltic in composition. Intermediate compositions are in the 55-63% SiO₂ range, and are "andesitic" in composition.

Two experiments are commonly performed that relate to the principles of igneous rock formation. The first experiment demonstrates a key principle of melting in the Earth, and the second relates to the process of crystallization.

1) A key aspect of magma generation (whether it occurs via heat addition, volatile addition, or decompression) is that the composition of the initial melt is typically different from the composition of the mantle or crustal rock that undergoes melting. This is called partial melting and it

simply means that when melting occurs in the Earth, the initial liquid (melt fraction) will be more silica-rich (more felsic) compared to the parent rock that is being melted.

A demonstration of partial melting is the squeezing of frozen grape juice. When squeezed, the liquid that oozes out is generally more purple- or grape-colored than the remaining frozen material. In other words, there is a difference in composition between the liquid (melt fraction) and the remaining frozen (solid) parent material.

2) A key aspect of igneous rock crystallization, as discussed above, relates to cooling rate, and its associated control on grain size. Although rocks can be melted in the lab, it requires highly specialized equipment and temperatures in excess of 800 °C. However, the relationship between cooling rate and crystal size can be demonstrated with a low melting point (and non-toxic) organic compound, thymol (oil of thyme), $C_{10}H_{14}O$.



Figure 1. Granite is a common type of intrusive, felsic, igneous rock, which is granular and phaneritic in texture.

Procedure

1. Grape Juice experiment

1. Open a canister of store-bought artificial grape juice.
2. Empty some of the contents into hands and squeeze.
3. Note that the liquid is a deep purple color, and the remaining solid has lost some of its purple coloration and is now more like clear ice.

2. Cooling Rate and Crystal Size

1. Sprinkle a layer of thymol crystals in the bottom of a Petri dish, just covering the bottom of the dish.
2. Set Petri dish on hot plate, in well-ventilated area.
3. Set heat of the plate on a very low setting, just enough to begin melting. Low heat is important, otherwise the crystals will volatilize.
4. Once melted, take the dish and set on a table to watch cool.
5. Repeat the above steps (2.1-2.3) with a second Petri dish, but once melted, take dish and set on top of an ice water bath.
6. Compare the crystal size between the Petri dish that underwent slow cooling on a table to the Petri dish that underwent rapid cooling atop the ice water bath.

Results

- 1) The grape juice experiment demonstrates the concept of partial melting. Where an initial liquid (melt) is typically of a different composition than the parent rock that undergoes melting.
- 2) The thymol experiment demonstrates the concept of igneous rock grain size as being related to cooling rate. Rapid cooling generates smaller crystals than slow cooling.

Applications and Summary

Igneous rocks are of substantial importance. Geologists identify and map intrusive igneous rocks for a variety of reasons.

Intrusive igneous rocks can be markers of certain kinds of ore deposits. For example, felsic to intermediate composition intrusive magma bodies can act as the heat sources that drive hydrothermal circulation systems, and concomitant precipitation within fractures (veins) of ore minerals including Cu, Mo, Au, Ag, and others. In contrast, mafic to ultramafic intrusions are associated with Cr, Pt, and Ni deposits.

Intrusive igneous rocks can also be markers of past magmatic activity. If magmas breach the surface, then volcanic eruptions occur. Therefore the recognition of intrusive igneous rocks will lead a field geologist to assess whether or not any associated volcanic rocks are present.

Intrusive igneous rocks are part of deciphering Earth's history. This is partly because intrusive igneous rocks are relatively easy to date using isotopic techniques, and because the type of igneous rock can be a marker of a past plate tectonic setting. For example, felsic rocks are characteristic of melting within the continental crust (*i.e.* intraplate magmatism). Intermediate rocks are characteristic of subduction zone settings. Mafic rocks are characteristic of mid-ocean ridges and continental rift zones.