Partial Melting and Magma Student Worksheet

Melting Minerals and Bowen's Reaction Series

Norman Bowen, a young petrologist from Canada, carried out a series of experiments in the early 1900s that changed the way geologists understood igneous rocks. His results help us to understand the origin of magmas, types of igneous rocks and volcanic eruptions.

Bowen used recently developed high temperature furnaces, petrographic microscopes, and chemical analysis methods to study minerals and their melting behaviour. He found that minerals melted at different temperatures. Felsic minerals melted at lower temperatures and mafic minerals at higher temperatures. This helped to explain the composition of magma, lava, and igneous rocks in different settings. The findings are summarised in the Bowen's Reaction Series diagram (Figure 1) which relates the mineral composition of magma to mineral melting points, arranged by temperature.

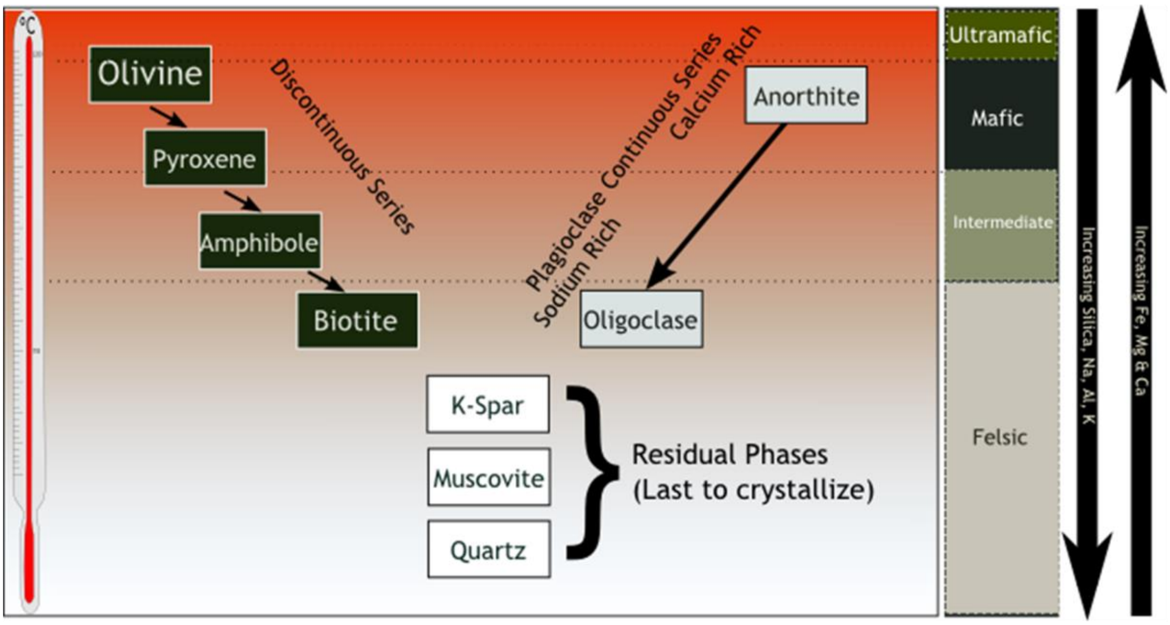

Figure 1: Bowen's Reaction Series shows the temperatures at which minerals melt. Those with a high melting point are on the top of the diagram. (Colivine 2011, public domain)

Making Magma

Bowen's reaction series explains why mafic magmas are so hot (up to 1250°C). High heat is required to melt the mafic minerals in Earth's mantle. Mafic magma is produced over hot spots in Earth's mantle like the Hawaiian Islands.

Cooler magmas (as low as 650°C) are produced when lower temperatures melt mantle rock. Only some of the mantle minerals melt. This is called *partial melting*. Partial melting of crust also contributes to felsic magmas. At lower temperatures, many felsic minerals and very few mafic minerals will become part of the melt that forms magma. Differences in pressure and the addition of water affect the melting point of minerals, but the order of melting remains the same.

Rock Compositions

Rocks are typically mixtures of minerals and are named based on their composition. As you can see in Figure 2, the compositions grade into each other. However, we can name an igneous rock based on the relative volume of each mineral and its texture.

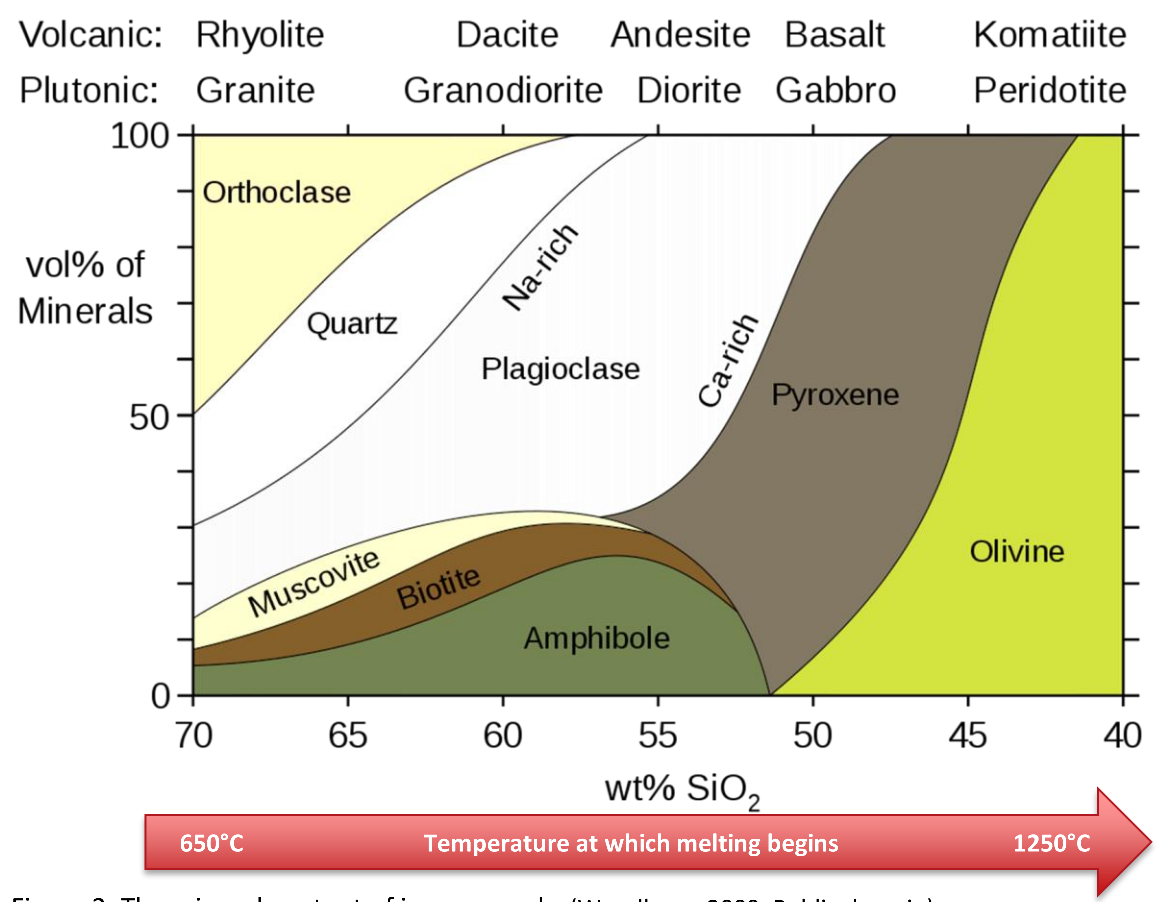

Figure 2: The mineral content of igneous rocks (Woudloper 2009, Public domain)

Volcanic rocks are those which cool relatively quickly at, or near, the surface and have a fine-grained texture. They are also known as extrusive igneous rocks.

Plutonic rocks cool slowly at depth, allowing larger mineral crystals to form. This gives them a coarse-grained texture. They are also known as intrusive igneous rocks.

Rocks with the same mineral content have different names according to their texture. For example, andesite and diorite have the same mineral composition, but cooled at different rates, resulting in differing texture.

Questions

1. Use the information above to predict characteristics of an **ultramafic igneous rock**

    a. What mineral(s) could it contain?____

    b. Is this rock relatively high or low in SiO_2?____________________________________

    c. Was this rock produced by a high or low temperature magma?__________________

2. Draw a vertical line on Figure 2 through the centre of **andesite**. Use this to determine its characteristics.

    a. What is the most common mineral in andesite? _____________________________

    b. Identify two other minerals you might find._________________________________

    c. What is the percentage of SiO_2?____

3. If a new volcano was detected with an estimated magma temperature of 700°C, would you expect to find mafic or felsic rocks on the surface near the volcano? Use Figure 2 to name a rock you might find.

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4. The temperature of Earth's mantle is approximately 1400°C at the base of the lithosphere (100 km deep). The temperature changes rapidly throughout the crust. Imagine that you are trying to drill 100 km through the crust to the mantle.

    Describe the composition of the first magmas your drill would typically encounter and how both temperature and magma composition would change as you drill further.

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5. In the famously un-scientific movie *The Core*, a team of scientists drills to Earth's core. Based on your response to question 4 and the fact that steel melts at 1400 - 1500°C, explain why it is not currently feasible to drill to Earth's core.

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6. Partial melting of mantle rock generates basaltic magmas. As the basaltic magma rises through the crust and cools, the magma becomes more andesitic. Use Bowen's Reaction series to explain this observation.

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Resources:

- For more information about magma see the AusEarthEd blogs Making Magma and Melting Minerals and the Origin of Magma.
- Related experiments are shown in the Aus EarthEd videos Making Magma and Partial Melting.
- Learn more about igneous rock formation with the ESWA video Igneous Rock Formation.
- To learn more about attempts to drill through Earth's crust, see this BBC article about the Kola Superdeep Borehole.