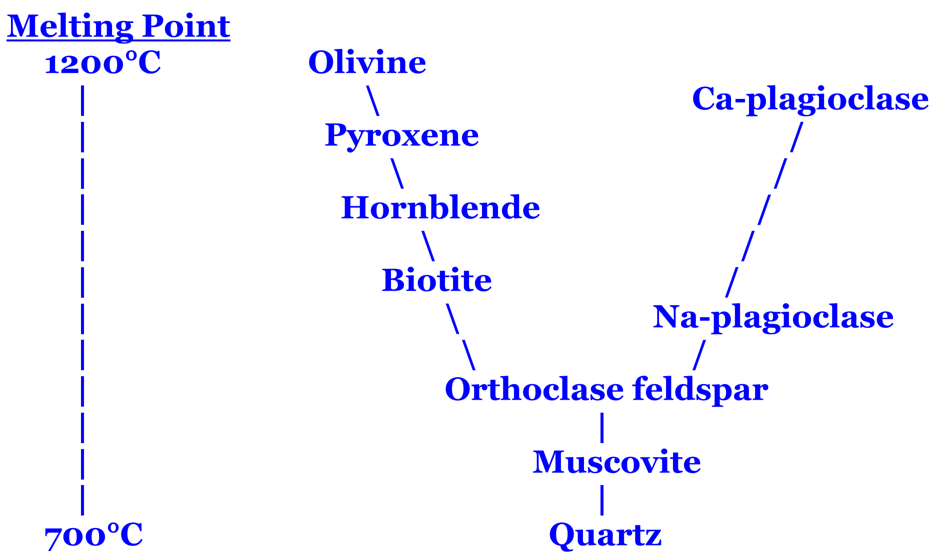
BOWEN'S REACTION SERIES

Bowen's reaction series is a means of ranking common igneous silicate minerals by the temperature at which they crystallize. Minerals at the top have a relatively high crystallization temperature, which means that they will be the **first** minerals to crystallize from a magma that is cooling. **IF** they are chemically compatible with the magma as it continues to cool, they will grow larger by addition of external layers of additional material. [They then may become the *phenocrysts* in a porphyritic igneous texture.] If they are chemically **in**compatible, they will react with the melt. What ultimately determines this chemical compatibility is in large part the total silica content of the melt.



Minerals on the left part of the "Y" of the diagram are what are called **ferromagnesian minerals**, because they contain iron (Latin: *ferrum*) and *magnesium* in their composition. This part of the series is referred to as the **dis**continuous series, since these minerals, if chemically incompatible with the melt as it cools, will usually completely react to form totally new minerals with different crystal structures: an olivine (island silicate) completely re-reacting with the melt may recrystallize into pyroxene (single-chain silicate), and a pyroxene may completely recrystallize into a hornblende (a double-chain silicate) or ultimately a biotite (a sheet silicate), **IF** enough free silica (and time!) is available during cooling. Thus, a rock that contains both olivine and hornblende is not in an equilibrium state, because these minerals form and are stable under different conditions; olivine and pyroxene are stable pairs, as are pyroxene and hornblende or hornblende and biotite. Biotite is the lowest-temperature iron-bearing silicate mineral that can form from a melt, and will be found only in rocks relatively rich in silica (e.g., in granites, or sometimes as phenocrysts in rhyolites, their volcanic counterpart).

The minerals on the right arm of the "Y" are the plagioclase feldspars, which form a continuous series from 100% Ca-plagioclase (anorthite) with the highest melting point, to 100% Na-plagioclase (albite) with the lowest melting point. The first crystals forming may entirely or only partially re-react with the melt, but without destroying the basic feldspar crystal structure. Very often, large plagioclase crystals in an igneous rock will have cores that are more calcium-rich than the outer layers, and this layering (called zonation) can be clearly seen under the microscope, or sometimes even with the naked eye for particularly large crystals – such as some of those in the steps in front of Miller Library.

The lower portion of Bowen's Reaction Series is dictated more by chemistry than is the upper part. Biotite, orthoclase feldspar and muscovite are the only minerals here that contain large amounts of potassium. These also have much higher silica contents than the minerals at the top of the series (e.g., pure olivine is about 38% SiO_2, while pure orthoclase is 65% SiO_2). It is this increase in silica content that lowers the melting point; note that quartz, at the bottom of the series, is, of course, 100% SiO_2, and has the lowest melting point (about 700°C).

As a result, rocks that crystallize from mafic melts (45-55% silica) will tend to be made up of minerals that are high in Bowen's reaction series - such as olivine, pyroxene and Ca-rich plagioclase feldspar. Rocks from felsic melts (>65% silica) will be composed mostly of minerals from the bottom of the series - biotite, Na-plagioclase, muscovite, orthoclase and possibly quartz. Rocks from intermediate magmas will contain minerals from the middle of the sequence. Worth noting is that these are the major minerals that will appear in the rocks; there will be numerous *accessory* minerals present that are not in Bowen's reaction series, such as magnetite (Fe_3O_4) or zircon ($ZrSiO_4$); these are present in small quantities only in most cases, but can be very informative about fine details of the rock history and properties.

The low melting points of minerals at the bottom of Bowen's Reaction Series means that at surface temperatures and pressures on Earth, they are closer to their normal fields of stability. Quartz, in fact, is completely stable at 20°C (68°F). Olivine, however, is not, and given the presence of water it will weather (break down) relatively rapidly. As a result, it is rare to find olivine in sediments or sedimentary rocks. Clays and iron oxides and hydroxides (e.g., hematite, limonite) are the weathering products of iron-rich silicate minerals, and are the mineral forms that **are** stable at low temperatures and pressures.

Thus, the lower minerals are in Bowen's Reaction Series, the more resistant they are to chemical weathering: this means that the rate at which they weather is slower than for minerals higher in the series. Quartz is subject only to dissolution, and in rare instances muscovite can actually form in soils as a weathering product from other minerals. All the other minerals in Bowen's Reaction Series, however, continually weather in the geologic environment, to forms that are more stable at the low temperatures and pressures of the Earth's surface, such as clays or iron and aluminum oxides and hydroxides (e.g., hematite, limonite, bauxite).