Ternary Phase Diagrams

- All of the chemical systems considered as examples thus far have been two-component systems. If a third component is added, another dimension is needed to show both composition and temperature in the phase diagram. Three dimensions are difficult to show on a two-dimensional sheet of paper. For example, the liquidus for each mineral in a three-component system is a surface. The most common procedure for three-component systems is to represent the "topography" of the **liquidus surface** using **temperature contours**. Several new features appear with the addition of a third component.

- **Two solids** can simultaneously coexist with (or crystallize from) a liquid over a range of temperatures, rather than just at a single eutectic temperature. At each temperature, the composition of the liquid in equilibrium with the two solids is fixed (so also are the compositions of the solids if they have variable compositions) and is given by a point on the **cotectic curve**, which is the intersection of the liquidus surfaces for the two solids.

- **Three solids** can coexist with a special **ternary eutectic** liquid at a unique ternary eutectic temperature. Ternary eutectics occur at the intersection of three cotectic curves. An example of a simple ternary eutectic system is **Mg_2SiO_4 - $MgAl_2O_4$ - $KAlSi_2O_6$** (**Fo**rsterite - **Sp**inel - **Le**ucite). For a rock consisting of the minerals forsterite, spinel, and leucite **in any proportions**, the first liquid that forms upon equilibrium heating appears at 1473°C and has the eutectic composition. The eutectic reaction is (Forsterite + Spinel + Leucite <--> Liquid). This is a **discontinuous reaction** that is **terminal** to the liquid.

- Ternary systems that contain solids of variable composition have some additional features of interest. The temperature at which the first liquid forms on heating depends on bulk composition. For any three-phase assemblage, more than one corner of the three-phase triangle may change composition upon heating or cooling. The lowest possible temperature for which a liquid can exist may be a **ternary minimum**, the bottom of a single trough-like cotectic curve.

- Horizontal, **isothermal sections** through a three-dimensional ternary liquidus diagram may be used to show exactly what phases will coexist (at equilibrium) for each bulk composition at the temperature selected. An isothermal section will consist of one or more of the following: (a) one-phase points giving the compositions of solids of fixed composition, (b) one-phase lines giving the compositions of solids that are two-component solid solutions, (c) one-phase regions giving the compositions liquids or solids that are three-component solid solutions, (d) two-phase regions filled with tie lines connecting the compositions of the two phases in equilibrium for bulk compositions in this region, and (e) three-phase triangles whose corners give the compositions of the three phases that coexist for bulk compositions that fall within the triangle. An isothermal section will intersect any liquidus surface along a curved line that will be the boundary to the liquid field on the isothermal section. An isothermal section will intersect any solidus surface along a curved line that will be the boundary to the solid field on the isothermal section.

- Two liquidus surfaces may also intersect along a **reaction curve**. A liquid on a reaction curve will simultaneously crystallize one solid and consume ("melt"?) the other solid as the temperature is lowered. The ternary system **$KAlSi_2O_6$ - $CaAl_2Si_2O_8$ - SiO_2** has a reaction curve that begins at the sanidine peritectic point on the **$KAlSi_2O_6$ - SiO_2** binary and extends to a **reaction point** at its intersection with the leucite-anorthite coetectic curve. The reaction point gives the composition and temperature of a **non-terminal** reaction (Leucite + Liquid <--> Sanidine + Anorthite). This reaction changes what phases can be found together in equilibrium, but does not eliminate any phase completely from the diagram in the way that a eutectic reaction does.

- It is possible to determine whether the intersection of two liquidus surfaces is a cotectic curve or a reaction curve by examining lines that are tangent to the curve. If the tangent to the curve passes **between** the compostions of the two solids in equilibrium with the liquid (on the curve at the point of tangency), then the curve is a cotectic or **even** curve. If the tangent to the curve does not pass between the compostions of the two solids in equilibrium with the liquid, then the curve is a reaction or **odd** curve. If the solids involved are solid solutions, then a curve may be a reaction curve for part of its length and a reaction curve for the rest of its length. A reaction curve will always terminate at a reaction point.