A PETROGENETIC GRID APPLICABLE TO CHONDRULE FORMATION. J. W. Snellenburg, Dept. of Earth and Space Sciences, State Univ. of New York, Stony Brook, N. Y. 11794

Some of the elemental abundances in meteorites may be the consequence of fractionations related to the distribution of elements among phases. Such fractionations can occur through the loss of a phase or a change in the relative abundances of phases. For example, condensation from a gas and isolation of the solids or the partitioning of Fe between metal and silicate. The interphase distribution of Fe, Mg, and Si is particularly important. Fortunately, there is both theoretical justification and experimental evidence that T, fO₂, and fS₂ control the partitioning of Fe among metal, silicate and sulfide [1-5,8,9,11,13], suggesting that a T-fO₂-fS₂ phase diagram of the system Fe-O-S-MgO-SiO₂ can serve as a petrogenetic grid appropriate to meteorites. Such a diagram defines the approximate boundaries of the intensive variable space in which mineral assemblages in meteorites are stable. In the following example of its use, the diagram will be used to illustrate how different melting and cooling histories of a chondritic composition can produce characteristic trends of Fe partitioning. Thus, the process of chondrule formation may have exerted a control over chondrule chemistry that was independent of any previous fractionation of chondrule parent material.

The grid can be constructed from available data [1,2,4-10,12-14]. Three-phase, silicate-metal assemblages found in chondrules are stable in divariant fields associated with the isobaric invariant point, olivine-silica-pyroxene-iron-liquid (OSPIL), in the system Fe-O-MgO-SiO₂ (Fig. 1) [13]. For example, the assemblage, olivine-iron-liquid (oil) corresponds to both olivine porphyries and barred-olivines. Many olivine + pyroxene chondrules would have the 4-phase univariant assemblage olivine-pyroxene-iron-liquid (OPIL). Equilibrated chondrites are represented by the assemblage olivine-pyroxene-iron (opi).

On Fig. 2, the point, OSPIL, has been superimposed on the stability fields of the system Fe-O. Figure 2 also shows the location of the isobaric invariant points at which the reaction curves of Fig. 1 terminate. The wüstite field defines the subsolidus stability of Fe²⁺ in the system Fe-O. The addition of SiO₂ to make fayalite expands Fe²⁺ stability to both higher (OSML) and lower (OSIL) fO₂ [5]. The addition of MgO further expands the stability field of Fe²⁺ bearing silicates. Because at any given T and fO₂ within this field, the compositions of the phases are fixed by the intensive parameters [9], the Fe/(Fe + Mg) ratios of the silicates define series of isocompositional lines subparallel to the wüstite field (see Fig. 4). Thus, on the completed petro genetic grid, Fig. 3, the activity of 'FeO' in the silicates decreases in all directions away from the wüstite field. The shaded areas define the stability of chondrule mineral assemblages containing Fe-bearing silicates. Several relevant calculated or measured reaction curves are also included on the diagram.

Figures 4-6 are schematic representations of the shaded areas of Fig. 3 at an arbitrary fS₂. Burgmann et al. [1] show that the main effect of increased sulfur fugacity in the system Fe-S is to depress the melting point of Fe³⁺. Therefore, the melting of Fe metal is represented by a dashed line. Figure 4a contains the mineral assemblages; Fig. 4b contains the corresponding chondrule types as well as representative isocompositional lines for olivine.
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Chondrule formation can be represented schematically by paths through T-fO2-fS2 space. The arrow in Fig. 5 is one limiting path which assumes that a chondritic melt forms and maintains equilibrium with the surrounding atmosphere during cooling. The first olivine appears as the melt passes from the liquid-only field to the liquid + crystal field. Along the indicated path, oxidation occurs and the silicates become progressively enriched in Fe^{+2}. Pyroxene appears at A, resulting in a 4-phase assemblage, pyroxene, olivine, liquid, metal. If the surroundings are able to buffer the fO2 as heat is extracted from the melt, the assemblage will remain at point A until the silicate liquid disappears. Under these conditions, points A and B are superimposed. If, on the other hand, the atmosphere is not externally buffered, both fO2 and temperature will change, allowing the melt to follow the path A'-B'. In the ideal buffered case, pyroxene of uniform Fe/(Fe + Mg) will crystallize. In the ideal unbuffered case, the Fe enrichment of the silicates will continue.

The equilibrium cooling history may not adequately describe chondrule formation in all cases. A transient high-energy event has been suggested as the chondrule forming mechanism [15]. A possible cooling history resulting from this is illustrated in Fig. 6. Let the "EQUILIBRIUM" line indicate the ambient oxygen fugacity as a function of temperature. If the solids are fused with sufficient speed to prevent oxygen equilibration, they would follow a path similar to the one indicated by the "FUSION" arrow. Since the heat source is transient, cooling begins immediately. In marked contrast to the equilibrium case, reduction of Fe occurs during first stages of the cooling history. The longer the melt remains outside the stability field of Fe silicates, the greater the reduction in the parent melt. Although during subsequent cooling, the progressive Fe enrichment of the silicates will occur and be preserved in zoned crystals, their compositions should reflect the Fe reduction.

In the limiting case where chondrule melts may be considered closed systems, the differences between products of distinct cooling histories are most pronounced. In the equilibrium case, mineral assemblages indicative of slower cooling (porphyritic olivine + pyroxene) should be the most Fe^{+2}-rich. In the non-equilibrium case, the phenocrysts of similar assemblages should be depleted in Fe^{+2}. Clearly other chemical fractionations will modify these trends, but, whatever the actual cooling history may have been, it is probable that: (a) Except under extraordinary conditions, any process that fuses material into chondrules causes redistribution of Fe between phases distinct from any fractionation that took place in the parent material. (b) The rate at which a chondrule melt cools governs the extent of iron redistribution. Consequently, the compositions and relative abundances of the Fe-Mg silicates in many chondrules are probably related directly to their cooling history.

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