PHASE EQUILIBRIUM CONSTRAINTS ON ANGRITE PETROGENESIS; J. Long

Lamont-Doherty Earth Observatory, Palisades, NY 10964, USA

Experiments [1] have shown that partial melting of devolatilized carbonaceous chondrite source regions can produce eucrite-like liquids at low-fO2 (IW-1) and low-SiO2, angrite-like liquids at higher fO2 (IW+2). The reason for this different behavior is reduction of ferrous iron at the lower fO2, which changes the normative character of the silicate source. Although the low fO2 experiments produced liquids closely resembling known eucrites, the match between liquids from the “high” fO2 runs and known angrites was not as close and aluminous augite (fassaite), a key mineral in angrites, was observed only at the solidus. In this paper phase diagrams are employed to illustrate the melting behavior of devolatilized chondrites minus variable amounts of iron as metal. These diagrams illustrate how partial melts of chondritic sources that have retained most of their iron can fractionate and become saturated with fassaitic clinopyroxene. However, such melts are too ferroan to have crystallized the observed clinopyroxene. Furthermore, olivine xenocrysts in LEW87051 and ASUKA881371 are too magnesian to have crystallized on any parent body capable of producing angrite-like melts, if the parent body formed by homogeneous reduction of chondrites. Some process, in addition to loss of iron and volatiles from chondrites, that increases Mg' and decreases normative silica is necessary to form the angrite source region.

Fig. 1 is a depiction of the olivine liquidus surface projected from the olivine component with boundaries curves drawn to agree with the liquid data (open squares) of [1]. The diopside solid solution field is taken from the data of [2,3] in the CMAS system as an approximation. These latter data show a dramatic increase in Al2O3 concentrations in coexisting diopside as SiO2 in the liquids decreases (~3% Al2O3 in di at the thermal divide M3 increasing to fassaite levels of 10.5 % near the liq+ol+di+an+sp invariant point). Analyses of augites (stars) from melting experiments on Angra dos Reis [4] show that solid solution in the natural system is at least as extensive as in CMAS. The heavy shaded curves A and M show the “high” fO2 melting paths of Allende and Murchison, respectively. In both cases melting begins at the liq+ol+di+an+sp pseudo-invariant point and, once augite is consumed, the melt composition migrates along the liq+ol+an+sp boundary curve dissolving ol and an while precipitating sp. Once an is consumed (~20% melting), the melt moves in the direction of the sp component across the liq+ol+sp surface until sp is consumed. In Fig. 2 tie lines between diopside (augite) and anorthite divide the diagram into a number of potential partial melting fields (I - IV). Bulk compositions in field I will begin melting at the liq+ol+di+an+opx invariant point; those in field IA begin melting along the liq+ol+sp boundary curve; those in field IV begin melting at the liq+ol+di+an+sp point; and those in fields II and III begin melting along the liq+ol+di+an boundary curve. These latter melts will have crystallization paths in opposite directions as determined by the M3 thermal divide. A vector, cutting across the melting fields, shows the direction and magnitude of Fe-loss from an Allende-like source. Curve B shows the fractional crystallization path of a partial melt from either a Murchison-like source or an Allende-like source with ~10% FeO loss beginning at the point at which sp is exhausted in the source. Curve B is merely inflected at the liq+ol+an+sp boundary curve because of the reaction of sp with liq. Once encountering this curve, fractionating liquids move onto the liq+ol+an surface and, subsequently, reach the liq+ol+di+an boundary curve, moving away from M3 toward low-silica compositions. Clearly, either low-degree melts of Murchison/Allende sources or differentiates of more extensive melts would closely match the compositions of the Lewis Cliff angrites [5] in terms of projection components (+ol) and would crystallize fassaite after ol + sp (optional) and ol + an.

Curve C shows the crystallization path for a melt of an Allende-like source that has lost ~15% of its Fe. Curve C crosses the trace of the liq+ol+di+an thermal divide in the liq+ol+sp field, so when a liquid fractionating along this path reaches the liq+ol+an surface it fractionates away from low-silica angrite compositions. Thus there is a limit to the extent of Fe-loss from chondritic sources which could be melted to yield angrite-like liquids.

Fig. 3 shows some of the constraints on chondrite melting imposed by Mg'[MgO/(MgO+FeO)]. The compositions of calculated olivine (liquidus and solidus) and pyroxene (solidus) are plotted versus the composition of the source and are contrasted with some of the natural mineral compositions in angrites [6,7]. The most magnesian olivine possible is the liquidus olivine of the completely molten source. Even with the extreme condition of total melting, xenocrystic olivines from LEW87051 [6] could not have formed from source that had lost any less than 40% Fe. Yet melts of such sources would be eucrite-like. Also, because an interval of fractional crystallization would necessarily precede the precipitation of fassaite from melts of a chondrite source, the most magnesian pyroxene would have lower Mg' than that predicted from applying KD to the sequence of partial melts. Because low degree melts would require the least amount of crystallization before reaching fassaite saturation, the most magnesian pyroxene can be approximated as that on the chondrite-Fe solidus. Fig. 3 shows that the solidus pyroxene has lower Mg' than the most magnesian pyroxenes in LEW86010 [7] for sources with Fe-loss that is less than ~30%. The high Mg' in both xenocrystic olivine and indigenous clinopyroxene requires
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a source with proportions of projection (normative) components similar to Murchison or Allende, but which has a much higher Mg'. This condition requires either a Mg/Si ratio significantly higher than the chondritic value, similar to the Earth's upper mantle [e.g., 8], or a source depleted in Fe but enriched in a CAI-like component.

REFERENCES


Fig. 1 and 2. Projection from Oi onto the Opx-La(larnite)--Ne,CA(CaAl2O4) plane. Shaded areas show limits of solid solution. Dashed vector shows % Fe loss. Fig. 3. Calculated liquidus and solidus phase compositions. KD for ol-liquid = 0.285; Kp for cpx-liquid = 0.22 [7]. Mineral compositions from [6,7].