A summary on recent petrographic investigation of a metal nodule in the Bondoc mesosiderite

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Inclusions in Bondoc metal nodule are classified into globular and angular inclusions [1]. In previous studies [2,3] we showed petrographic features of these inclusions. The globular inclusions are spheroidal in shape and mainly consist of devitrified glass. This suggests that the peak reheating temperature exceeded liquidus temperatures of such inclusions. Angular inclusions are irregular in shape and consist of pyroxene, plagioclase and silica of various sizes. Phosphate is often located on the surface of angular inclusions, protruding into the surrounding metal. The texture suggests that the peak reheating temperature did not exceed the liquidus temperatures of the constituent minerals. Various textures in globular and angular inclusions suggest that they cooled very rapidly after the reheating. It is possible that the metal nodule experienced the highest reheating temperature and the fastest cooling among all the mesosiderites. Hence, it is important to clarify its thermal history. There are a number of poorly-understood features which may provide useful information on the thermal history.

(1) Formation of phosphate using Ca in plagioclase

Usually Ca-phosphate in mesosiderites is considered to have been produced using Ca in pyroxene [4].

$$3CaMgSi_2O_6 + 2P + 5FeSiO_3 = Ca_3(PO_4)_2 + 3MgSiO_3 + 8SiO_2 + 5Fe$$

Here, P is in solid solution in the metal.

But Ca in plagioclase may also be used for the Ca-phosphate formation.

$$3CaAl_2Si_2O_8 + 2P + 5FeO = Ca_3(PO_4) + 3Al_2O_3 + 6SiO_2 + 5Fe$$

where FeO is actually in pyroxene and Al_2O_3 may be incorporated in pyroxene and chromite or exists as cordierite. It is not known if this is possible thermodynamically. Circumstantial evidence for this reaction in the metal nodule in Bondoc is high Al activities suggested by the presence of (a) cordierite, (b) high-Al pyroxene, and (c) high-Al chromite. As a corollary, plagioclase is absent (or rare) in inclusions with cordierite. It is not yet known under what conditions cordierite becomes stable over plagioclase.

(2) Formation of chromite

It was mentioned by [1], that there are two populations of angular inclusions in a Bondoc nodule; one is chromite-rich and another is chromite-poor. This was confirmed by observation of our nodule. Chromite in chromite-rich inclusions exists, in many cases, on the rim of the inclusions, suggesting that Cr was derived from the metal.

$$4FeSiO_3 + 2Cr = FeCr_2O_4 + 4SiO_2 + 3Fe$$

Here, Cr is in solid solution in the metal and $FeSiO_3$ is the end member of pyroxene solid solution.

In other inclusions, chromite is located in the peripheral part of inclusions, but not on the rim, often enclosed by narrow plagioclase. These suggest that there were multiple generations of chromite, produced by multiple reheating events. It is not yet known why there are chromite-rich and chromite-poor inclusions.

(3) Formation of narrow plagioclase

Often, plagioclase is observed as narrow rims on high-Al chromite and/or on inclusions. In the case of the rim plagioclase on chromite, the texture suggests that they formed using Al in the chromite. Ca was probably released at high temperatures where Ca-phosphate disintegrates. The silica activity is always 1 in the Bondoc nodule. Hence the narrow phosphate rims on chromites may have formed at high temperatures, although the thermodynamic evaluation has not been made. In the case of narrow plagioclase rims on inclusions, the textural observation does not suggest such a formation mechanism, but we speculate that they also formed at high temperatures under high activities of Al, Ca and Si oxides.

(4) Massive plagioclase

Compositions of massive plagioclase show little intra-grain variation in the interior of an inclusion but show large inter-inclusion variation, ranging from ~An#65 to ~An#88. (Rim of massive plagioclase often shows higher An#, which will be discussed elsewhere.) Often, massive plagioclase contains small silica inclusions [3] which were explained by sub-solidus exsolution based on the phase diagram of [5].

Recently, we noticed that the excess silica (the abundance and the grain size of silica inclusions) increases with decreasing An#. This can be explained if the silica solubility in plagioclase increases with decreasing An#. This tendency has been suggested for lunar rocks [5]. We are of the opinion that massive plagioclase was largely molten at the peak reheating temperature and cooled rapidly through the solidus temperature. In contrast to lunar rocks which preserve excess silica in plagioclase, however, silica is exsolved in massive plagioclase in the angular inclusions in the Bondoc metal nodule. This requires additional thermal processing.

(5) Formation of silica

Silica minerals (crystallographic information is not available) are abundant in angular inclusions in the nodule. Many of them are compositionally homogeneous with low Al (~0.1 mol. % Al). But some contains Si-Al-Ca-rich materials of irregular shape and the host silica mineral contains higher amounts of Al (>0.4 mol. % Al). The former is explained by formation at subsolidus temperatures as a by-product of phosphate formation. The latter is explained as an igneous product during quick solidification of a melt which contained abundant silica (that was produced in previous reheating events). Since angular inclusions are considered to have been partially molten, we expect that some parts of silica may remain solid at the peak temperature and overgrown by newly crystallized silica. But such overgrowth has not been found yet.

Overall, the petrographic observation suggests multiple reheating events experienced by mesosiderites. The young ages of mesosiderites [6,7] suggest that the heat source is not internal, like ^{26}Al. The first author is of the opinion that inductive heating due to changing solar wind magnetic field is likely.

References

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