

An attempt to reproduce petrographic features of mesosiderites

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Introduction

Reheating of mesosiderites is yet poorly understood. Recent studies suggested that (1) the heat source was located on/near the surface of the parent body because the peak temperatures are correlated with the cooling rates [1]. (2) Accretion of molten metal was not the heat source because a primitive mesosiderite contains small spheroidal metal which was presumably solid at accretion [2]. Also, spheroidal shape of large metal nodules suggests that the nodules were solid at the time of accretion. (3) Reheating occurred multiple times, which is mainly based on the presence of partially molten and/or idiomorphic phosphates [3]. This is because phosphate in mesosiderites was originally produced at subsolidus temperatures (less than ~1000 °C) by oxidation of P in the metal (reaction-1: $3\text{CaMgSi}_2\text{O}_6 + 5\text{FeSiO}_3 + 2\text{P} = \text{Ca}_3(\text{PO}_4)_2 + 3\text{MgSiO}_3 + 5\text{Fe} + 8\text{SiO}_2$ [4]) and hence another heating to above the solidus, is required for melting the phosphate. Therefore, the first author of this abstract is of the opinion that induction heating due to changing solar-wind magnetic field is a hopeful heating mechanism, but this is not widely accepted at present.

To elucidate the reheating history, we attempted to reproduce petrographic features of mesosiderites by heating mesosiderite simulants. By heating to ~1300 °C, P is released by the backward reaction of the reaction-1, and mainly enters the metal by solid solution. This is associated with oxidation of metallic Fe to ferrous Fe, which forms pyroxene if cooled slowly or glass if cooled rapidly. Upon cooling below T*~1000 °C, the reaction-1 forms phosphate and metallic Fe. Mesosiderite pyroxenes clearly show features associated with this redox reaction. Therefore, by experimentally reproducing petrographic features of pyroxene in mesosiderites, we may be able to quantitatively understand the reheating history. As explained below we have not succeeded in reproducing salient petrographic features of mesosiderites at the time of writing this abstract, but some constraints can be placed on the reheating history. More experiments will be done by December and new results will be presented at the meeting.

Experimental

Bulk diogenite/eucrite, silica, phosphate and metal were mixed at a proportion which resembles the bulk mesosiderite compositions, and sealed in a quartz tube under vacuum. The charges were heated to a peak temperature, held for 10~20 minutes and cooled at a constant rate. This heating schedule was varied so that the resultant simulants look like mesosiderites. The peak temperatures range from 1270 °C to 1400 °C. The cooling rate was 900 °C/hour for quick cooling. For slow cooling, it is 117 °C/hour from 1333 °C to ~1050 °C and 2.1 °C/hour down to 650 °C. Cooling is faster at lower temperatures down to the room temperature. Thick polished sections were made and observed with a SEM (JSM-6510LA). Quantitative measurement of mineral compositions was made by EDS; the results are not accurate but are fairly precise. So far, 7 samples with various heating schedules were produced.

Results

All the samples show small metal grains in which fine silicate fragments are scattered. This means that the integrated grain-boundary diffusion length during the heating runs is less than that of real mesosiderites. In quickly cooled samples, a large amount of glass exists, which indicates that the cooling rates are faster than those of mesosiderites. P is mainly present as solid solution in the metal and phosphate is absent. This means that the backward reaction of reaction-1 proceeded efficiently during the heating above T*. The Fe/(Fe+Mg) ratios in the glasses are nearly constant at ~0.6. This ratio is much higher than that of diogenite pyroxene, and cannot be explained by partial melting/fractional crystallization. They cannot be explained by the production of ferrous Fe by the backward reaction of the reaction-1 either. We do not have a reasonable explanation for such a high ratio in glasses.

In slowly cooled samples, some phosphate exists. But it is not abundant and the size is small. The reaction-1 suggests that either, (1) the CaSiO_3 activity was low, (2) the FeSiO_3 activity was low, (3) the P activity was low, or (4) the cooling rate was too fast for the reaction to proceed efficiently. All the pyroxenes show normal zoning. Even in the sample with some phosphate, reverse zoning of pyroxene is not observed. Since reaction-1 requires that reverse zoning is associated with the phosphate formation, this is an interesting situation which merits further investigations.

In some samples residual (unmolten) pyroxene remains. In others, all the silicates were molten and reprecipitated upon cooling. Since real mesosiderites almost always contain residual pyroxene, this means that temperature-time history of the former samples was appropriate.

Pyroxene in some of the samples show high Al concentrations which increases toward the rim. High Al pyroxene is observed in some mesosiderites. But the Al zoning in real mesosiderites is complicated; both increase and decrease in Al toward the rim are observed. These are probably related to the phosphate formation reaction which remove Ca from silicates, resulting in high Al activities. In contrast, Al in pyroxene in the simulants seems to be caused by delay in plagioclase formation due to fast cooling rates.

It is often observed that residual pyroxene is overgrown by magnesian pyroxene in the simulants. This contrasts with real mesosiderites where pyroxene overgrowth is Fe-rich. This is presumably due to pre-existence of abundant chromite in mesosiderite matrix, compared with HED achondrites [5].

Plagioclase in the simulants is either absent (quickly cooled samples), or smaller (slowly cooled ones) than that in real mesosiderites. Since plagioclase precipitates after pyroxene, this suggests that the cooling rate of the simulants near the solidus was too fast compared with that of real mesosiderites.

Summary

Although we have not successfully reproduced the main petrographic features of mesosiderites, some constraints have been obtained on the reheating time-temperature relationship. Metal, plagioclase and phosphate observations suggest that the cooling rate should be slower. Glass compositions and lack of reverse zoning in pyroxene are hard to explain. Better understanding of mesosiderite petrology is needed. We are aiming at production of larger phosphate and reverse zoning in pyroxene, which will hopefully shed light on the reheating of mesosiderites.

References

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