FORMATION OF STONY-IRON METEORITES: LABORATORY SIMULATIONS

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Stony-iron meteorites offer important clues to the geophysics of meteoritic parent bodies, because they represent interfaces between metal and silicate portions of differentiated planets. Pallasites are fairly straightforward to interpret: the mixture of olivine embedded in once-molten nickel-iron presumably represents a core/mantle interface. Mesosiderites are much more mysterious. They are breccias consisting of basalt fragments and iron metal, which appears to have infiltrated as a liquid. It is very difficult to understand where and how such material formed, because basalt is a low-density partial-melt product expected to be at planetary surfaces, while high-density iron would sink to a planetary core. In a differentiated parent body, one would expect surface basalts to be separated from the iron core by the thick mantle of olivine that composes the largest fraction of the planet.

One explanation for the origin of mesosiderites is a differentiated parent body with a basaltic crust bombarded by iron meteorites [1]. Impact melting created the mesosiderites at or near the surface. But this explanation does not solve the problem of the missing olivine: iron impactors must have formed by the earlier fragmentation of other differentiated bodies, hence should have yielded much more olivine than iron, so subsequent bombardment of the mesosiderite parent should have included substantial amounts of olivine as well as iron. An alternative model [2] has a basaltic crust sinking through a molten mantle to the molten core, where iron infiltrates the pores of the basalt and is quenched by the cooler silicates.

Any model of mesosiderite formation must grapple with the problem that the iron appears to have infiltrated the basalt as a liquid. The melting temperature of basalt is lower than that of iron, even given the high sulfur content of some mesosiderites. Thus if the basalt came to equilibrium with the molten iron, it too would melt, and then float to the surface of the iron. On the other hand, if the basalt chilled the iron too quickly, the metal would have been unable to penetrate the basalt. However mesosiderites formed, a disequilibrium process balanced the tendencies of the liquid iron to melt the basalt and of the basalt to chill the iron.

In order to define the conditions under which stony-irons could form, we have attempted to simulate their formation in the laboratory. The metallic component of our experimental charges is generally 60 wt.% Fe and 40 wt.% S, which allows melting at less than 1400°C, the limit of our furnace. This sulfur abundance is reasonable given that some stony-irons have significant troilite components. A reducing flowing atmosphere (90% argon, 10% hydrogen) is maintained in the furnace to prevent oxidation of iron. Although sulfur is somewhat volatile, about 30% sulfur remains in the metallic melt at the end of each experiment.

Simulating pallasite formation is relatively easy because the melting point of olivine is higher than that of metal. Forcing a raft of olivine crystals into the molten iron, as might occur at a core mantle interface [3], proved impractical. Instead, a previously fused metallic charge was placed on top of a layer of olivine crystals in a cylindrical alumina crucible. The sample was remelted at 1350°C for 16-20 hr. The metallic liquid and olivine crystals became intimately intermingled, yet the buoyant olivine crystals did not rise and crowd at the surface despite the lack of an upper restraining force. The quenched samples exhibit a pallasite-like texture (see photo), supporting the core-mantle formation hypothesis.

Simulating mesosiderite formation is more difficult. We cannot melt the iron in the presence of basalt, because the basalt would have melted as well. Instead we first melt the metal at 1350°C in an alumina crucible. The crucible is then raised to an accessible position near the top of the furnace where we plunge basalt chips (epoxied to the end of an alumina rod) into the metallic liquid. The iron tends to chill before it can intimately invade the basalt, so we immediately reinsert the crucible containing the molten iron and the basalt into the hot zone for times varying from 0 to 300 sec to simulate various rates of cooling in the parent body. The basalt melted completely when the sample was reinserted for >120 sec, while the metal solidified without filling in the the interstices among the basalt fragments for cases with reinsertion for ≤15 sec. Mesosiderite-like textures were produced in intermediate cases (30 and 60 sec): Molten iron invaded the interstices, yet melting of basalt occurred only on the edges of some of the silicate fragments. These results indicate a narrow quench window for the formation of mesosiderites in any model that invokes a liquid phase.

References: [1] Wasson, J.T., and Rubin, A.E., 1985, Nature 318, 168. [2] Greenberg, R., and Chapman, C.R., 1984, Icarus 57, 267. [3] Wood, J.A., 1981, Lunar Planet. Sci. XII, 1200.

Photo: A section of a simulated pallasite about 1 cm across with olivine crystals a few mm in diameter.

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