VOLATILE-BEARING PHASES IN THE PRECURSORS OF IRON-TYPE COSMIC SPHERULES

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Introduction: Iron-type (I-type) cosmic spherules consist of magnetite and wüstite and can also include FeNi metal [1] and are thought to form by melting and oxidation of extraterrestrial metal grains during their atmospheric entry [2,3]. Although I-type spherules comprise only 1-6% of micrometeorite collections [4,5] they are important since they are the most common MMs recovered from ancient sediments and have been identified within rocks as old as 2.7Ga [6]. Despite the significance of I-type cosmic spherules, the nature of their precursors and identity of their sources is only poorly understood.

We report the results of a study of the mineralogy, textures and compositions of 88 Antarctic I-type cosmic spherules that suggests the presence of non-metallic phases within their precursor dust grains, including volatile-bearing minerals. The results suggest that the precursors of many I-types were multi-phase assemblages.

Results: The 88 I-type spherules are 60 to 230 μm in diameter and were recovered from amongst 1200 cosmic spherules from moraine at Larkman Nunatak in the Transantarctic mountain range. All the studied I-types are dominated by wustite (FeO) and magnetite (Fe_3O_4), with 47% also retaining an FeNi metal bead within a shell of iron oxide. Spherules containing FeNi metal (MET spherules) have oxide shells dominated by wüstite with minor magnetite (<5 vol%), whilst metal bead free-spherules (OX spherules) contain higher abundances of magnetite.

Amongst MET spherules 23% contain re-entrant metal beads with veins of FeNi metal extruding from metal beads into the grain boundaries between surrounding wüstite dendrites. The remaining MET particles have smooth metal beads and no metal within the wüstite shell. One re-entrant MET spherule also has a vesicle within its metal bead.

The iron oxide shells of MET spherules are dominated by non-stoichometric wüstite (90 vol%) with minor magnetite present as small (<5 μm) equant grains. Both wustite and magnetite have finite but low Ni contents of 0.1 to 1.5 wt% with wustite more Ni-rich than magnetite. In some particles wustite contains up to 1.5 wt% Cr. Beads contain only FeNi metal (10-70 wt% Ni) with no detectable S, P or Cr. Smooth and re-entrant particles show the same range of metal and oxide compositions. Metal extrusions from beads in re-entrant particles often contain ~1 wt% more Ni than their coexisting metal beads but have the same Ni/Co ratios.

Discussion: I-type cosmic spherules are thought to form by progressive oxidation of FeNi metal during entry heating, with the oxide liquid growing at the expense of liquid metal [2,3]. The formation of re-entrant metal beads is, however, contrary to Fe-O and Fe-Ni-O phase relations since it indicates the injection of liquid metal between solid wüstite crystals and yet FeNi metal liquid should crystallise at higher temperatures than wüstite. The presence of sparse S, C or P within the precursor dust grain, in the form of sulphide, carbide or phosphide mineral inclusions, however, can decrease the solidus temperature of FeNi metal to below that of wüstite enabling the formation of metal veins. Since no phosphate is observed within re-entrant particles, carbide and/or sulphide, which will degas during oxidative heating, are the most likely reasons for the low solidus temperature of metal.

Although volatile-bearing mineral have not been found in I-types, the extrusion of metal veins in re-entrant spherules may may be evidence for their existence since vesicle formation driven by degassing of volatile-bearing phases will generate an over-pressure forcing metal between wüstite grain boundaries. Capillary action can be discounted as a viable mechanism for extrusion due to the large contact angle of Fe-Ni metal with solid oxides of >90º [7].

The observation that re-entrant metal beads are observed in 23% of I-types is broadly consistent with sulphide and carbide abundances in meteorites and suggests that the precursors of many I-types contain volatile-bearing phases. The presence of significant Cr within wüstite in some I-types also suggests that chromite inclusions may have been present.

Conclusions: The precursors of I-types were dominated by FeNi metal but also contained inclusions of sulphides or carbides and chromite. These phases are present within metal in both chondrites and iron meteorites, however, sulphide is found more commonly as small inclusions within chondritic metal, whilst carbide is present within plessite in iron meteorites. The multi-phase assemblages of I-type spherules complicates identifying their parent body affinities since their bulk compositions will not correspond to the composition of metal in any particular meteorite type.

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