THE ONSET OF SULFIDE CORE FORMATION IN OXIDIZED ASTEROIDS

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Summary: To investigate the physical mechanisms involved in oxidized asteroidal core formation, we have conducted partial melting experiments with fragments of a Rumuruti-type (R) chondrite to observe the evolution of sulfide melts. Sulfides completely melt as they reach the silicate eutectic temperature and rapidly migrate to wet the grain boundaries of matrix silicate phases via capillary action. This mechanism stands in contrast to typical models of metallic core formation and other percolative liquid models, which both involve extensive silicate melting at higher temperatures and pressures. These findings provide important considerations for evaluating asteroid 16 Psyche's petrogenesis, as well as for other differentiated asteroids and planetesimals with high concentrations of oxygen and sulfur.

Introduction: Updated models of core formation and new insights into the compositional variation of asteroidal cores are critical to interpret remote data collected from the surface of asteroid 16 Psyche. Once proposed to be an exposed metallic core, the nature of 16 Psyche's origin remains unclear, as preliminary estimates of its density are much lower than that expected of Fe,Ni metal alloy and are inconsistent with a fully intact, denuded metallic core [1]. Alternative explanations for 16 Psyche's observed characteristics are required to understand its origin. To this end, several recent works have reported evidence for processes of sulfide-dominated core formation in asteroids based on trace element systematics in resititic meteorites [2], sulfide major element chemistry in Rumuruti-type (R) chondrites [3], and thermodynamic modeling of planetary differentiation in some carbonaceous chondrites [4]. These works collectively imply that oxidized and sulfur-rich parent bodies have cores composed primarily of sulfide liquids rather than Fe,Ni metals. If 16 Psyche is instead an asteroidal core composed primarily of sulfides rather than metal, this would largely resolve inconsistencies with its estimated density.

While the fractionation of liquid sulfides from residual silicates is tentatively supported in the meteoritic record by trace element geochemistry [2-3], the physical parameters of this process and its timing are largely unconstrained. This work investigates the onset of partial melting in the Fe-Ni-S system of oxidized, sulfur rich meteorite parent bodies and the physical mechanisms involved in producing sulfide-dominated cores.

Methods: We have conducted a series of partial melting experiments with a fragment of the R chondrite PRE 95410,33 to observe the partial melting of sulfides and migration of sulfide liquid. Experiments were coordinated with microscale X-ray computed tomography (μ-XCT) analyses both prior to heating and after each heating step. To begin, the sample was sealed in an evacuated silica glass tube, placed vertically into a box furnace, raised to 900°C for 48 hours, then quenched in water. After analysis, the process was repeated at a target temperature of 1,040°C, the predicted silicate eutectic for R chondrites [5]. Upon completing the experimental series, the sample was extracted from the silica glass assembly, bisected, and polished for petrographic investigation at the LPI SEM Facility.

Results: Comparative analysis of the fragment of PRE 95410,33 shows minimal changes in the distribution of sulfides up to 900°C. However, by 1,040°C, >90% of sulfide grains (10-500 μm diameter) are no longer present. Their original locations are visible as void spaces in μ-XCT images. Silicate grain boundaries in the matrix, chondrules, and lithic fragments are resolvably brighter in μ-XCT, consistent with migration of sulfide liquids and formation of a melt network, but most are below the 4-μm voxel resolution. The two polished sections of the experimental product confirm that sulfide liquids migrated from their original locations to wet the grain boundaries of silicate phases.

Discussion: The redistribution of sulfides from their original locations to line the grain boundaries of silicates throughout the sample provides compelling evidence that oxidized, sulfide-dominated core formation in asteroids may begin at lower temperatures than reduced, metal-bearing counterparts. Depending upon the fraction of sulfide liquid relegated to its core, oxidized asteroids can differentiate to form cores composed of pyrrhotite and pentlandite ± awaruite. This process can explain the trace element systematics observed in oxidized restitic meteorites [2] as well as paleomagnetic evidence for a weak dynamo in the R chondrite parent body [6]. This process may also account for the low density of 16 Psyche if its petrogenesis involved the formation of an oxidized and sulfur-rich core. The onboard gamma ray and neutron spectrometer in the Psyche mission's scientific payload should be able to distinguish the products of this process from those of metallic core formation. If Fe/Ni ratios for surficial sulfides and/or metals are ≤1, this would provide strong evidence that 16 Psyche is the product of oxidized, sulfur-rich core formation.

References:

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