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SPECIAL COLLECTION: BUILDING PLANETS: THE DYNAMICS AND GEOCHEMISTRY OF CORE FORMATION

The effects of shear deformation on planetesimal core segregation: Results from in-situ X-ray micro-tomography

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Abstract

It is well accepted that the Earth formed by the accretion and collision of small (10–100 km), rocky bodies called planetesimals. W-Hf isotopic evidence from meteorites suggest that the cores of many planetesimals formed within a relatively short time frame of ~3 My. While a very hot, deep magma ocean is generally thought to have been the driving mechanism for core formation in large planetary bodies, it inadequately explains differentiation and core formation in small planetesimals due to temperatures potentially being insufficient for wide-scale silicate melting to occur. In order for these planetesimals to differentiate within such a relatively short time without a magma ocean, a critical melt volume of the metallic (core-forming) phase and sufficient melt connectivity and grain size must have existed to attain the required permeability and lead to efficient core formation. Shear deformation may increase the connectedness of melt and the permeability, and thus could have been a major contributing factor in the formation of planetesimal cores. This deformation may have been caused by large impacts and collisions experienced by the planetesimals in the early solar system. The purpose of this work is to test the hypothesis that shear deformation enhances the connectivity and permeability of Fe-S melt within a solid silicate (olivine) matrix, such that rapid core formation is plausible. A rotational Drickamer apparatus (RDA) was used to heat and torsionally deform a sample of solid olivine + FeS liquid through six steps of large-strain shear deformation. After each deformation step, X-ray microtomographs were collected in the RDA to obtain in situ three-dimensional images of the sample. The resulting digital volumes were processed and permeability simulations utilizing the lattice Boltzmann method were performed to determine the effect of shear deformation on connectivity and permeability within the sample. The resulting permeabilities of the sample at various steps of deformation are the same within uncertainty and do not exhibit a change with increasing deformation. Additionally, the migration velocity calculated from the permeability of the sample is not high enough for segregation to take place within the time frame of ~3 My. In addition to further constraining the mechanism of core formation in planetesimals, the image processing techniques developed in this study will be of great benefit to future studies utilizing similar methods.

Keywords: Core formation, microtomography, permeability, lattice Boltzmann