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ON THE POSSIBLE ROLE OF ELEMENTAL CARBON IN THE FORMATION OF REDUCED CHONDRULES.

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INTRODUCTION Recent experiments(1,2) have been designed to produce chondrule textures via flash melting while simultaneously studying the nature of chondrule precursors. However, these experiments have only been concerned with silicate starting material. This is a preliminary report concerning what effects elemental carbon, when added to the silicate starting material, has on the origin of chondrules produced by flash melting.

EXPERIMENTAL TECHNIQUE A Type IA chondrule composition was synthesized from ground olivine (San Carlos), orthopyroxene, diopside and albite and sieved to form two grainsizes, 23-45μm and 125-250μm. The calculated liquidus (3) is 1703°C. Carbon, in the form of graphite (submicrometer to 200μm) and diamond (0.5μm), was added to the silicate precursor material. Amounts of carbon used were 1%, 3%, 5%, 7% and 10% by weight. Total weight of pellets before melting was 25mg. All charges were flash melted at 1750°C using the technique of (1,2) and the total time from initial melting to quenching was approximately 25 minutes. Experiments were performed at the Experimental Petrology Labs at the JSC. The fO_2 within the furnace was maintained with a mixture of CO and CO_2 at -1.5 log unit below the IW buffer. Samples were initially imaged as whole charges and metal grains were removed from the surface for later analysis. Charges were then sectioned and analyzed on a JEOL 8600 superprobe at the Rutgers University Microanalysis Lab.

EXPERIMENTAL RESULTS Imaging of uncut charges revealed that the surfaces of charges with no carbon added to the precursor contained no metal grains. However, charges that contained carbon in the precursor material often have numerous metal grains, up to several 100's of μm in diameter, on their surfaces. Also present on the surfaces of some of the charges that contained graphite within the starting material was rare grains of graphite that were often associated with tiny metal and SiO_2 grains.

Experiments that used the 23-45 μm grainsize produced typical Type IA chondrule textures whereas the 125-250μm starting grainsize produced PO textures similar to Type IIA chondrules. All charges that did not contain any carbon have olivine phenocrysts normally zoned from Fo_{94} to Fo_{89}. These same charges contain numerous relict San Carlos olivines that are overgrown by the same, normally zoned, melt-grown olivine. Rare, inclusion-free, metal grains exist and the charges contain appreciable amounts of Na within the mesostasis.

Charges that contained carbon within the starting material all have textures similar to the control experiments. All of these charges contain phenocrysts that have compositions more reduced than the control experiments. Charges that contained 1% carbon have olivines zoned from Fo96 to Fo94. Charges that contained 3% carbon have olivines normally zoned from Fo98-Fo94. Charges that contained 5% carbon have olivines normally zoned from Fo99.50 to Fo98. Charges that contained 7% and 10% carbon within the starting material have olivines with composition similar to charges that contained 5% carbon within the starting material. No difference in mineral chemistry was observed either between graphite or diamond and between fine and coarse grainsized starting material.

Relict San Carlos grains are present in all charges, however, in many charges the relict grains are not pure San Carlos olivine. Many relict grains have regions and veins of more reduced olivine and often have inclusions of metal grains and thin veins of Fe-metal. These charges all contain far more metal than the control charges and the metal often has inclusions of silica. The metal grains vary in composition from pure Fe-metal to Fe-metal with varying amounts of Ni and metal abundance appears to increase with increases in the amount of carbon in the starting material. The mesostasis of charges with carbon added to the starting material contain appreciable amounts of Na, analogous to the control charges, with no changes in Na correlated to variations in the amount of carbon added to the starting material.

DISCUSSION It is clear from our experiments that at 1 atm in a gas of IW -1.5 elemental carbon added to the silicate precursors produces a charge that is much more reduced in chemistry than charges without added carbon. The more carbon added to the starting material, the greater the reduction. However, as amount of carbon in the starting material exceeds 5%, no additional reduction of the silicates occurs. All of our experiments contain relict olivine grains, that have inclusions of metal and could be considered analogous to dusty olivines. Such relict grains have only been produced in the lab when carbon has been added to the silicate precursor. Most of these relict grains have zoning that is reversed from the center of the relict to the center of the overgrown olivine. However, the zoning then becomes normal from the center of the overgrowth to the edge of the overgrowth. We interpret this observation to be the product of initial reduction caused by the reaction of elemental carbon with oxygen in the charge to produce an initially more reduced intrinsic fO_2 than the surrounding gas. Once the carbon has all reacted, the charge equilibrates with the ambient gas, thus producing a more oxidized chemistry.

Another result of these experiments is the production of metal grains, many of which have inclusions of silica. Such inclusions in metal grains have been observed in natural reduced chondrules (4). Their formation has been argued to be the result of reduction followed by oxidation during chondrule formation (5). Unpublished results (6) show similar silica inclusions in metal in charges that were formed in a gas with an fO_2 of IW -4 without carbon added. However, these same experiments produce silicates that are more oxidized than either our experiments or natural, reduced chondrules. These same experiments have also not produced relict, dusty olivine grains that were produced in our experiments. Therefore, our data support the concept that the intrinsic fO_2 of the chondrule precursor may have played a more controlling role in the formation of reduced chondrules than the ambient nebular gas.

CONCLUSIONS Organic and elemental carbon were present within the early solar nebula (7,8). It has been postulated that organic material may be an important "glue" enabling the mineral grains of the chondrule precursor to stick together. Our experiments show that elemental carbon could have played a key role in the formation of reduced chondrules and that reduced chondrules, silica inclusion in metal grains, and relict, dusty olivine grains could be interpreted as evidence for carbon within chondrule precursors. Chondrule redox may therefore be controlled by the intrinsic fO_2 of the precursors and not the fO_2 of the surrounding nebular gases. However, we cannot rule out the possibility that the production of reduced chondrules may require both a reducing agent in the precursors and a reducing nebular gas.

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