NATURAL REDUCTION OF LUNAR IRON OXIDE

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Background: It has been known for many years that the metallic iron in agglutinates was likely formed during micrometeorite impacts on the lunar surface by a reduction process in which iron oxide in the melt was reduced forming the fine-grained, mostly single domain iron [1,2]. This reduction may be caused by solar wind-implanted hydrogen at the surfaces of the small grains which melt to make agglutinates, although hydrogen has not really been confirmed as the reducing agent and carbon may also play a role. Other kinds of iron on glass and crystals have been described, including iron interpreted as impact splash [3]. Experimental formation of reduced iron on simulated lunar glass has also been demonstrated [4].

Glass balls at Van Serg: Double drive tube or core 79001/2 collected at Van Serg Crater contains some extremely mature soils, possibly the most mature in the lunar collection [4]. These core soils are also unusually rich in solar wind-implanted hydrogen [5] The Van Serg area was originally noted by the Apollo 17 astronauts to have a remarkable number of glass balls in the soil: "There's a lot of - oh, 2-3, 4-millimeter-size fragments of glass we're kicking up all over the place. Little glass balls." [6]. The description of the double drive tube [7] refers to mm to cm-size glass balls, some of which are hollow and some of which have metallic luster over significant parts of their surface. We have investigated one of these hollow glass balls with the SEM. An interesting feature of this glass ball is the presence of scattered amoeboid-shaped clusters and chains of metallic iron on both the exterior and interior surface of the glass, and on the walls of broken vesicles. Fig. A and B shows two clusters from the interior surface of 79002,2125. Grain size of the iron in these clusters ranges from about 0.5μm to about 5 μm. While the general appearance is similar to a splash or splatter, close examination shows that these clusters are made up of approximately equant grains, some with incipient crystal faces, which are coalescing together.

Iron on experimentally reduced ilmenite: A project carried out by Carbotek, Inc. included a number of experiments to extract oxygen from simulated lunar ilmenite using hot hydrogen gas as a reducing agent [8]. A sample of Minnesota ilmenite (provided by P. Weiblen) was reduced at 1000°C, well below the melting temperature of pure iron (1535°C). (Samples were provided by C. Knudsen and M. Gibson of Carbotek, Inc.) SEM photos of the reduced ilmenite grains are shown in Fig. C and D. These grains exhibit two important features. First is the porous nature of the reduced grain where oxygen has been partially removed from the ilmenite structure. Second is the abundance of metallic iron on grain surfaces. While not shown in these views, metallic iron is also abundant in the interior of the reduced ilmenite grain where it is often in subparallel platelets.

Discussion: The synthetic iron bears a remarkable resemblance to the lunar iron. Both show the tendency toward coalescence of originally equant iron. The process has not gone as far on the synthetic runs because the pores break up the surface. We interpret both of these textures to result from enhanced mobility of iron atoms at the host grain surface with a strong tendency to form crystals which coalesce into larger forms. The synthetic run demonstrates that this process can take place at temperatures well below the solidus of metallic iron. Previous experimental studies [4] on glass were done at much higher temperatures (1450°C). We suggest that this reduction and coalescence on grain surfaces may be a major way in which large grains of metallic iron form in the lunar regolith as it matures. The correlation of the abundant glassy balls at Van Serg with the high hydrogen content and the high content of coarse-grained iron (up to 0.5 wt % in the mature part of 79001/2 [9]), as well as the reported metallic luster on some of these balls suggest that much of this coarse-grained iron was created by reduction of iron oxide in the glass, possibly at iron subsolidus temperatures. The iron observed here would be included in the Fe^{o}_{mm} of [9] and may in fact be the major contributor. One implication is that this may be a natural demonstration that iron can be reduced and oxygen can presumably be liberated from lunar material under reasonable temperature conditions and also very rapidly. Whether the iron oxide in the glass was reduced by the relatively abundant hydrogen in the Van Serg soils, the carbon, or by some process such as partial volatilization remains to be shown.

References: [1] R. Housley et al. (1973) Proc. Lunar Planet. Sci. Conf. 4th, pp. 2737-2749. [2] R. Morris (1976) Proc. Lunar Planet. Sci. Conf. 7th, pp. 315-335. [3] D. McKay et al. (1970) Proc. Ap. 11 Lunar Sci. Conf., pp. 673-694. [4] J. Carter and D. McKay (1972) Proc. Lunar Sci. Conf. 3rd., pp. 939-970. [5] R. Bustin and E. K. Gibson (1990) GCA, (submitted). [6] Muehlburger et al. (1973) USGS Interagency Report Astrogeology 71, p. 302. [7] Schwarz (1986) Lunar News, pp. 5-6. [8] M. Gibson and C. Knudsen (1988) Proc. ASCE-AIAA Space 88, pp. 400-410. [9] R. Morris et al. (1989) Proc. Lunar Planet. Sci. Conf. 19th, pp. 269-284.

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