IMPACT MELTING OF ORDINARY CHONDRITE REGOLITHS AND THE PRODUCTION OF FINE-GRAINED Fe^0.

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Introduction: The detailed study of individual lunar soil grains provides evidence that the major optical properties of the lunar surface are primarily related to the production of fine-grained (< 20 nm, super-paramagnetic) Fe-particles in agglutinitic impact melts and to iron-rich vapor deposits on the surfaces of individual grains [1]. These Fe-rich materials are derived from oxidized species due to high post-shock temperatures in the presence of solar-wind derived H_2 [2]; part of the Fe-rich grain surfaces may also be due to sputtering processes [1]. Identical processes were recently suggested for the optical maturation of S-type asteroid surfaces [3, 4], the parent objects of ordinary chondrites (OCs). OCs, however, do not contain impact-produced soil melts [5], and should thus also be devoid of impact-triggered vapor condensates. The seeming disparity between [3, 4] and [5] can only be understood if all OCs resemble relatively immature impact debris, akin to numerous lunar highland breccias [5, 6, 7]. It is possible to assess this scenario by evaluating experimentally whether impact velocities of 5-6 km/s, typical for the present day asteroid belt, suffice to produce both impact melts and fine-grained metallic iron.

Experimental Conditions: We used 125-250 µm powders of the L6 chondrite ALH85017 [8]. These powders were aliquots from fines that were produced by collisionally disrupting a single, large (461g) chunk of this meteorite during nine impacts [9] and by subjecting the resulting rubble to an additional 50 impacts, akin to [10]. As a consequence, the present shock-recovery experiments employ target materials of exceptional fidelity (*i.e.*, a real chondrite that was impact pulverized). The target powders were packed into tungsten-alloy containers to allow for the potential investigation of freshly produced, fine-grained iron and impacted by stainless-steel and tungsten flyer plates; the packing density varied between 38 and 45% porosity. Peak pressures ranged from 14.5 to 67 GPa and were attained after multiple reverberations of the shock wave at the interface of the silicate powder and metal container. Pressures in the 50 to 70 GPa range should be fairly typical for asteroid impacts at ~ 5-6 km/s [*e.g.*, 7, 10], yet we note that these pressures refer to those at the projectile/target interface only and that most crater ejecta on OC parent-bodies will have experienced much lower stresses.

Results: As illustrated in Fig. 1a, all initial porosity disappeared by 14.5 GPa and a dense network of interlocking grains, some disaggregated and mechanically deformed, resulted. Melting commenced at grain boundaries at 27 GPa and was prominent at 38.1 GPa (Fig. 1b; these melts pluck readily during thin-section manufacture giving rise to the apparent "pores" in Fig. 1b). The melts also contain numerous opaque spherules (light color in this BSE image) composed of either metallic Fe-Ni or FeS (and occasionally W from the target container). Fig. 1c shows that substantial fractions of the entire target are molten at 65 GPa. Note again the abundance of small metal or sulfide droplets in the melts. A high-magnification image of these opaques is illustrated in Fig. 1d (65 GPa) illustrating that their size-range extends to < 0.1 µm, and most likely to the sizes of super-paramagnetic particles (<20 nm).

Figure 2 illustrates the total amount of melt produced as a function of peak pressure. Note that the melting curve for the OC is bracketed by lunar basalt and terrestrial dunite, consistent with the target's modal mineralogy (less feldspar in the OC than in lunar basalts and less olivine in the OC compared to dunite). There appears to be nothing unusual about the melting behavior of ALH85017 and therefore OCs in general. Electron-microprobe analyses of the glasses in the 67-GPa experiment (Fig. 3) reveal substantial compositional heterogeneity, representing arbitrary mixtures of component minerals, including monomineralic melts, which are typical for grain-boundary melting. In addition, the average melt-composition is deficient in Fe relative to the target's bulk composition, because Fe^0 and FeS form immiscible melt droplets that were avoided during the glass analyses. The metallic droplets reveal substantial compositional variety as well, with Ni varying from 5 to 48% (average 30% Ni), consistent with variable taenite / kamacite ratios; the sulfide blebs vary in S from 32 to 36% (average 35%).

Discussion: These experiments contribute to two significant issues regarding ordinary chondrites:

(I) Impact melts undoubtedly form at currently prevailing impact conditions in the asteroid belt [7, 10]. Although our experimental melts do not resemble the bulk soil compositionally, slightly higher pressures or finer-grained targets would promote melt homogenization about the target average. In any case, equivalent melts are not observed in OCs. As a consequence, it is unlikely that OCs reflect current asteroidal surfaces. Instead, they represent materials that were not substantially processed by micrometeoroids. OCs seem to be much more analogous to lunar highland breccias and the relatively ancient lunar mega-regolith, than they are to lunar soils and genuine soil breccias as already suggested [*e.g.*, 5, 6, 7 and others].

(II) OCs and S-type asteroid surfaces contain abundant metallic Fe and Fe-sulfides, unlike lunar rocks. Upon melting by impact, these phases form immiscible melts that are disseminated as small droplets throughout the dominant silicate melt; droplet sizes include objects < 0.1 µm and extend most likely to super-paramagnetic particles. These processes occur at relatively modest impact speeds. Therefore, it is not necessary to appeal to *in situ* reduction or sputtering processes [3, 4] for the production of fine-grained Fe^0 on asteroid surfaces. It is necessary only to modify the grain-size distribution of preexisting phases to exert a dramatic effect on the optical properties of S-type asteroids. This may also explain why wholesale melting of OC materials [11] does not reproduce the spectral characteristics of S-type asteroids.

Additional characterization via FMR, IR, and Mössbauer methods of the experimentally produced melts hopefully will confirm the above suggestions and contribute to a refined

Impact Melting of Ordinary Chondrite Regoliths: F. Hörz *et al.*

understanding of the "space weathering" processes on asteroids.

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Figure 1.