RELATIONSHIPS AMONG PHYSICAL PROPERTIES AS INDICATORS OF HIGH TEMPERATURE DEFORMATION OR POST-SHOCK THERMAL ANNEALING IN ORDINARY CHONDRITES.

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Introduction: Collisions were crucially important for the compaction of asteroidal-sized bodies, including those from which ordinary chondrites were derived. After primary accretion, parent bodies would have retained significant amounts of ancient porosity, owing to their small diameters. High velocity impact deformation alters the physical properties of materials in two ways: by reducing porosity, and by introducing foliation, both as a result of compaction [1-8]. During a collision on a high porosity (e.g. >20-25%) body, porosity is reduced, but in low (≤2-3%) porosity bodies, shock cracks the brittle silicates which actually reintroduce porosity to a rock. Approximately 5-7% porosity can be reintroduced by such microcracking [9, 10]. Foliation, or planar preferred grain orientations, in ordinary chondrites has been observed and the strength of foliation correlates with increasing shock intensity recorded in a rock [4,5,8]. All of this leads to a simple model in which shock intensity and metal shape foliation is inversely related to porosity.

Separating an ordinary chondrite's history into discrete accretionary, thermal metamorphic, and impact episodes is convenient, but the reality is much more complex. Ruzicka et al. [11] examined olivine microstructures by transmission electron microscopy and optical microscopy. They concluded that some chondrites experienced significant post-shock annealing, deformation while hot, or both, consistent with other evidence for high-temperature deformation [7,12,13] and post-shock annealing [12,14,15]. $^{40}Ar/^{39}Ar$ ages in many of these chondrites date to the metamorphic era of ordinary chondrite history. In reality, decoupling thermal metamorphism and impact may not be fully realistic. In this work, we test the simple model relationship between shock intensity, metal shape foliation, and porosity and reexamine their relationships in ordinary chondrites in light of growing evidence for complex relationships between impacts and thermal processes in ordinary chondrites.

Methods and Results: Porosity [9], foliation strength [6], and petrographic observations [11] are used to interpret the thermal metamorphic-shock histories of a suite of sixteen ordinary chondrites, ten of which are inferred by others [e.g. 7, 11-15] to have experienced either impact-related deformation at high temperatures or significant post-shock annealing. We find that these ten ordinary chondrites possess foliation and porosity characteristics that are inconsistent with a simple model of shock compaction (i.e. they possess low porosity, low shock stage, and little foliation).

Conclusions: There are two possible explanations for low-porosity, weakly foliated, and apparently weakly-shocked chondrites: (1) post-shock annealing helped obliterate olivine strain and/or metal foliation in these meteorites, and (2) shock occurred under warm conditions different from other chondrites, which allowed more reduction of porosity. Both explanations may be correct. Annealing and recovery could have obliterated strain and caused a reduction in shock stage [11,15] and elevated temperatures would have permitted additional compaction during deformation [1-3]. These features can be explained by the formation of annealed chondrites at depth directly below an impact crater on an already warm parent body. Transport to deeper or shallower portions and to different cooling environments of warm bodies could have occurred. Relying on shock stage, as determined by observations of petrographic thin section, alone for cooling and shock history models of ordinary chondrites may be inadequate. More broadly, it appears that the parent bodies of H, L, and LL chondrites all were compacted while these bodies were undergoing thermal metamorphism. Shock compaction under warm conditions likely helped lithify the planetesimals.

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