CLUES TO THE INTERNAL STRUCTURES OF SMALL ASTEROIDS FROM METEORITE BRECCIAS

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Introduction: Spacecraft images and geophysical data from the small S-type S asteroids, Eros, Gaspra, and Ida, show that they are fractured, coherent bodies [1], not the classic "rubble pile" asteroids that are predicted from models of catastrophic asteroidal impacts, family and satellite formation, and studies of asteroid spin rates, and other diverse properties of asteroids and planetary craters [2]. Reconciling these conflicting views is crucial for asteroid science and hazard mitigation.

Impact histories of Eros, Gaspra, and Ida: Three possible impact histories can be envisaged for small asteroids. They may have formed as impact shards from much larger bodies, as rubble piles from catastrophic collisions, or they may be largely intact bodies that accreted 4.6 Gyr ago. Ida and Gaspra, like many asteroids, are members of families [3] and formed from impact debris in catastrophic impacts. Other small asteroids, like Eros, are probably derived from families. Hydrocode and N-body models used to simulate catastrophic impacts suggest that asteroid family members >1 km are all rubble piles [4]. Modeling of Vesta's family [5] and an extrapolation from the sizes of the largest ejected boulders around impact craters [6] suggest that the largest single blocks in family-forming impacts are kilometer in size. We conclude that most 1-100 km asteroids formed as rubble and that S asteroids like Eros, Gaspra, and Ida were later consolidated.

Consolidation of breccias and asteroidal rubble: Brecciated ordinary chondrites and many other meteorite breccias testify to a long history of impact fragmentation and consolidation by alteration, metamorphism, melting and impact processes. Some breccias were lithified in regoliths but many appear to have formed after disruption and reaccretion events as asteroid impact models would predict. Some L and LL chondrite breccias were lithified by metamorphic processes, and a few breccias were lithified by injected impact melt, but most are regolith and fragmental breccias that were lithified by mild or moderate shock, like most lunar breccias. We suggest that the impact processes that converted impact debris into meteorite and lunar breccias may have consolidated asteroidal rubble in the same way. Small asteroids that formed as gravitational aggregates developed regoliths that partly filled internal voids during impact-induced seismic shaking. Consolidation of regolith-filled voids beneath large craters may have helped to lithify asteroidal rubble to form a more coherent body. Impacts consolidate porous chondritic powders by forming bridges of silicate shock melt that glue grains together during mild shock [7], and by friction and pressure welding of silicate and metallic Fe,Ni grains. Fractures on Ida created by antipodal impacts [8] are concentrated in and near large craters consistent with this model.

References: [1] Sullivan R. et al. (2002) In *Asteroids III* (Bottke W. F. et al., eds) pp. 331-350. [2] Asphaug et al. (2002) In *Asteroids III* (Bottke W. F. et al., eds) pp. 463-484. [3] Ivezic Z. et al. (2002) *Astronomical Journal* 124: 2943-2948. [4] Michel P. et al. (2004) *Icarus* 168:420-432. [5] Asphaug E. (1997) *Meteoritics & Planetary Science* 32:965-980. [6] Lee P. et al. (1996) *Icarus* 120:87-105. [7] MacCarthy K. A. et al. (2002) Abstract # 1720, Lunar & Planetary Science Conference. [8] Asphaug E. et al. (1996) *Icarus* 120:158-184.