SIDEROPHILE AND OTHER GEOCHEMICAL MIXING RELATIONSHIPS AMONG HED-METEORITIC BRECCIAS: NEED FOR RECOGNITION OF REGOLITHIC HOWARDITE AS A DISTINCT SUBTYPE

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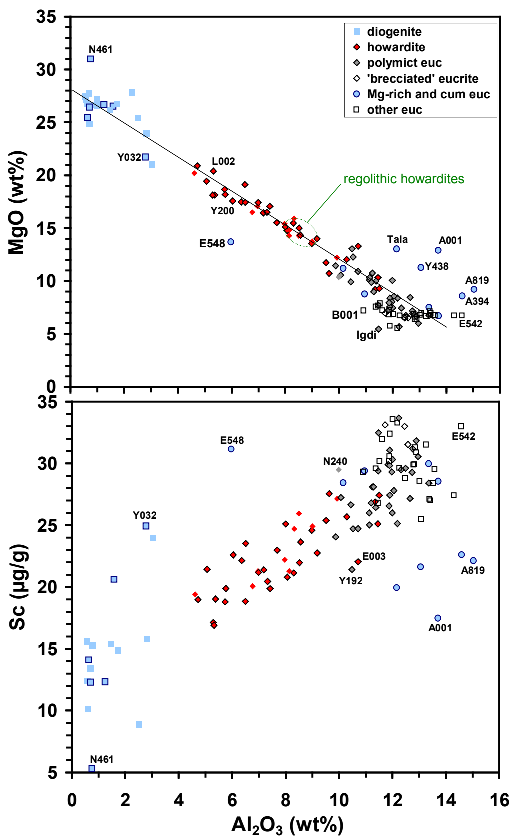
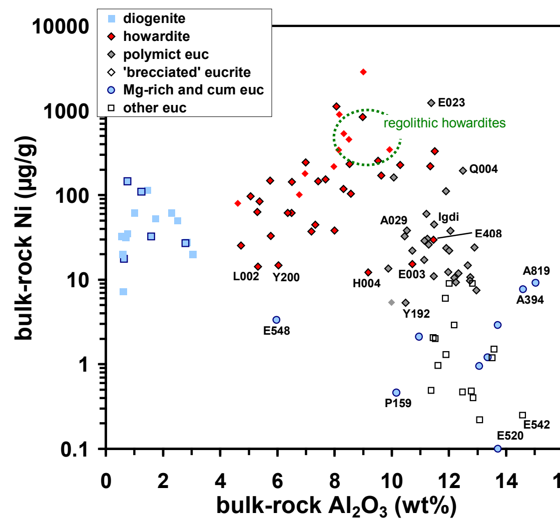
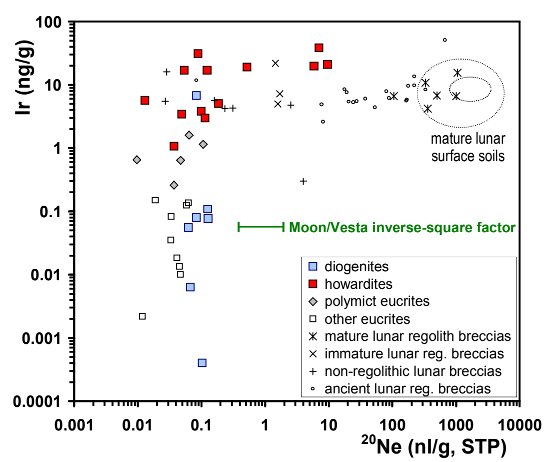
Introduction: Using INAA and other methods, we [1] have determined the major- and trace-element bulk compositions of ~ 100 (depending upon pairing issues) separate HED meteorites, mostly polymict breccias. Most revealing are results for siderophile elements, and particularly Ni (in polymict materials, we usually manage to detect Ni even without resort to RNAA). Among howardites, Ni shows a diffuse but highly significant correlation with Al_2O_3. Howardites in general are not regolith breccias. A small group of regolithic howardites feature, along with definitive solar gas enrichments and other traits, distinctively high Ni.

Nuances of the well-known HED mixing trend: Fig. 1 shows our results, plus a lesser number of literature analyses [sources far too numerous to cite, but e.g., 2,3], for bulk-rock Al_2O_3 vs. MgO and Sc in HED meteorites. Symbols bounded by dark lines denote new analyses from this work. For each meteorite, the average of our 1-3 analyses is plotted (avg. analysis mass: 0.35 g; avg. per-meteorite mass: 0.50 g). Also included are averaged literature data for up to 10 howardites and 13 diogenites, shown by symbols without dark-line boundaries. These and similar diagrams show that cumulate eucrite compositions are diverse, but on average have slightly higher Al_2O_3, much higher MgO, much lower Sm (as an exemplar of incompatible elements), and lower Sc, compared to noncumulate eucrites. The overall mixing trend, in nuance, points toward an average cumulate/noncumulate ratio for the eucrite component within the howardites similar to the cumulate/noncumulate ratio among eucrites, per se. Fig. 2 shows, using the same database, Al_2O_3 vs. Ni. The correlation among howardites is diffuse but clearly significant.



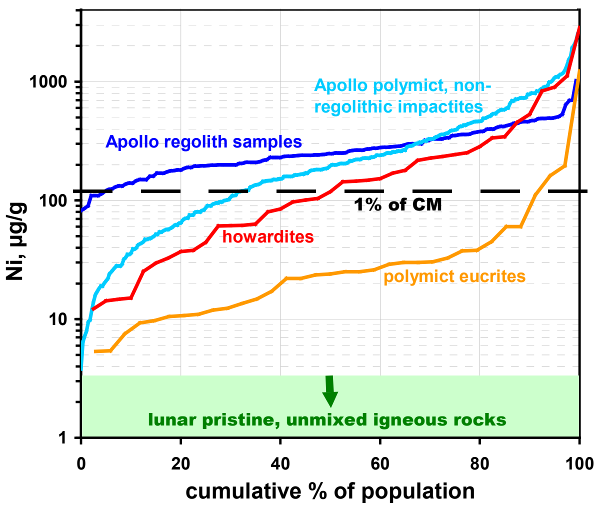


A key constraint from noble gases: Fig. 3 shows contents of ^{20}Ne, as exemplar of solar noble gases (literature data, mainly from data base of L. Schultz [4]),



vs. Ir for HED meteorites. Even allowing for the inverse-square factor in solar wind flux, only four of the most Ir- (and Ni-) rich howardites have gas contents remotely similar to lunar regolith breccias.

Siderophile elements: Fig. 4, using the same database as Figs. 1 and 2, shows that the full, undivided



population of howardites shows much greater Ni diversity than lunar regolithic samples. Instead, the howardite Ni diversity pattern resembles that of non-regolithic lunar polymict materials. Polymict eucrites tend to be enigmatically Ni-poor, in comparison to lunar impact-mixed materials.

Regolithic howardites represent a distinct subset: The quintet of regolithic howardites that show solar gas enrichments (or in the case of Malvern, evidence of former gas enrichments [5]) are distinctive in several other ways, such as:

• more Ni-rich than all but one (Molteno) of the gas-poor howardites,

• rich in glasses, especially spheroidal glasses [6],

• rich in recognizable chondritic (esp. CM) clasts [7].

Furthermore, the few (seven) howardites with between 340 and 1200 µg/g Ni consistently show some combination of the other traits suggestive of regolith origin.

Implications from the limited diversity of regolithic howardites: Another characteristic of the known regolithic howardites is a strong clustering of their compositions near 8-9 wt% Al_2O_3; with all that implies (e.g., MgO near 14 wt%) in terms of the HED mixing trend. Of the 9 howardites with >300 µg/g Ni, 8 have Al_2O_3 confined to 8-10 wt%; 7 are in the range 8-9 wt% (the most severe outlier, MAC02666 at 11.5 wt% Al_2O_3, 330 µg/g Ni, and noble gas composition unknown, barely qualifies as Ni-rich). For comparison, howardites in general have Al_2O_3 contents evenly spread across the range 4.6-11.5 wt%. Apparently, the regolith of the parent asteroid (Vesta?) was at one time a well-stirred, near-uniform mix of ~64 wt% eucrite with ~36 wt% diogenite. In contrast, Hubble ST studies indicate that the surface of modern Vesta is highly diverse in Al_2O_3, with a large orthopyroxene+olivine region dominating one hemisphere, and basalt dominating the other [8].

Assuming the HEDs are reasonably representative of the ancient (i.e., pre-vestoid-launch) crust of Vesta, the clustering of regolithic howardite composition is difficult to explain unless most of the deep-origin diogenite component was brought to the ancient surface by a single major impact, after which smaller-scale cratering, with no further major excavation of diogenite, yielded an efficiently homogenized surface that lasted throughout the several hundred-million-years period of subsequent HED-meteoritic blending. Such a single-excavation model may also help to explain why diogenites, in marked contrast with eucrites, are seldom polymict; and why Al_2O_3-poor (diogenite-dominated) howardites consistently lack major siderophile enrichments. A much later (<1 Ga: [9]) great impact launched the vestoids and effectively resurfaced Vesta.

Conclusions: Hewins [10] long ago made the point that not all howardites are truly regolithic. Our newer data, especially for siderophile elements, have made the situation significantly clearer. There should no longer be any excuse for persisting with classification and terminology that obfuscate HED-petrologic relationships by lumping all howardites, as a class, with the small and compositionally distinctive subset that truly are regolithic breccias. From the limited compositional diversity among the regolithic howardites, we infer that the diogenitic component was probably brought to the ancient surface of the parent asteroid (Vesta?) almost exclusively by a single great (and deep) ancient impact, rather then piecemeal through a series of many shallow impacts.

References: [1] Warren P. H. et al. (2009) *MAPS*, submitted. [2] Barrat J-A. et al. (2007) *GCA 71*, 4108. [3] Mittlefehldt D. W. and Lindstrom M. M. (2003) *GCA 67*, 1911. [4] Patzer A. et al. (2003) *MAPS 38*, 1485.[5] Kirsten T. and Horn P. (1977) in *Soviet-Amer. Conf. on Cosmochemistry of the Moon and Planets*, NASA SP-370. [6] Olsen E. J. et al. (1990) *Meteoritics 25*, 187. [7] Zolensky M. et al. (1996) *MAPS 31*, 518. [8] Gaffey M. J. (1997) *Icarus 127*, 130. [9] Marzari F. et al. (1996) *Astron. Astrophys. 316*, 248. [10] Hewins R. H. (1982) in *Workshop on Lunar Breccias and Soils and their Meteoritic Analogs* (eds. G. J. Taylor and L. L. Wilkening).