MAKING CRUST IN THE ASTEROID BELT: EVIDENCE FROM GRA 06128/9 AND BRACHINITES

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GRA 06128/9: Since their discovery at Graves Nunataks icefield during the 2006/2007 Antarctic Search for Meteorites field season, GRA 06128 and GRA 06129 have received considerable scientific attention. Their elevated modal abundances of oligoclase (>75%), blocky or slab-like character, granoblastic textures and 'andesitic' bulk compositions set them apart from all other meteorite classes. It has been suggested, based on whole-rock and mineral compositions, ^{207}Pb-^{206}Pb ages, Δ^{17}O, and highly siderophile element (HSE) data, that GRA 06128/9 represent fragments of ancient (4.52 ±0.06 Ga), evolved asteroidal crust [1]. Here, we critically assess how the GRA 06128/9 meteorites formed, how extensive such materials were in the early Solar System and whether there is a link between GRA 06128/9 and brachinite meteorites [2].

Methods: For mineral characterization, we used Cameca SX-50 and JEOL 8900 Superprobe electron microprobes, as well as an UP213nm laser-ablation system coupled to an Element 2 ICP-MS [1]. Whole-rock Os isotopic and highly siderophile element abundance measurements were performed via N-TIMS (Triton) and solution-based ICP-MS (Element 2) methodologies, respectively [1]. Oxygen isotope analyses were performed via laser fluorination [3]. Spectral analysis of finely ground powders of the meteorites was made at the Brown University RELAB facility [4].

When And How Was Evolved Asteroidal Crust Formed? The GRA 06128/9 meteorites are characterized by granoblastic textures and two-pyroxene thermometry indicates equilibration temperatures between 650-850ºC [1,5], implying significant metamorphism subsequent to igneous emplacement of the samples in their parent body. Since Pb diffusion occurs in phosphates at ≥500ºC [6], the ^{207}Pb-^{206}Pb age determined on Cl-apatite of 4.52 ±0.06 Ga indicates that crystallization, thermal metamorphism and cooling below 500ºC all occurred within 100 Ma of Solar System formation [1]. The ^{147}Sm-^{143}Nd age for the meteorites of 4.55 ±0.09 Ga [7] and the ^{26}Al-^{26}Mg model age initial of 4.564 Ga [5] support this chronology.

Petrogenesis of the meteorites is consistent with derivation from an oxidized, volatile-rich and undifferentiated chondritic source [1]. Non-modal batch melting models imply 10-30% partial melting to generate the GRA 06128/9 meteorites, in broad agreement with experimental work on the role of partial melting in L6 chondrites (Fig. 1).

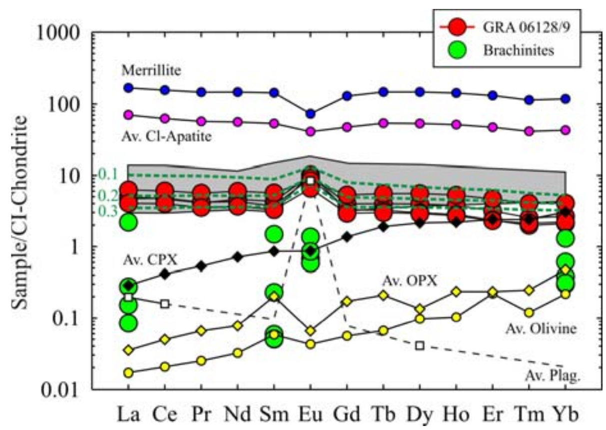

Figure 1: *Rare earth element (REE) patterns for the GRA 06128/9 and brachinite meteorites (after [1]) and average mineral REE abundances in GRA 06128/9. Also shown are 10-14% partial melt experiments for the Leedey L6 chondrite (shaded field, after [8]) and for non-modal batch melting models (green dashed lines: 0.1-0.3 = 10-30% partial melting) assuming chondritic mineral modes and abundances of the REE.*

HSE concentrations within a factor of 2 or 3 of chondritic abundances support the model of derivation of the GRA 06128/9 meteorites from a parent body that experienced only partial melting (Fig. 2). Sulphide segregation likely played an important role in generating the fractionated HSE patterns and in distributing these elements within the GRA 06128/9 parent body.

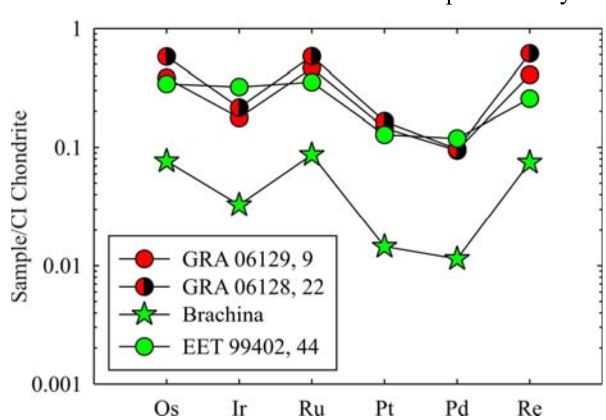

Figure 2: *Highly siderophile element patterns for GRA 06128/9, Brachina and EET 99402 (brachinite).*

A Link Between GRA 06128/9 And Brachinites? Based on the similar O-isotope compositions of leached whole-rock powders of GRA 06128/9 [1] and brachinites [9], it has been suggested that there may be a genetic or process-related link between these meteorite groups [1,2]. This relationship is supported by trace element compositions (Fig. 1). There is also remarkable agreement between the fractionated HSE patterns of GRA 06128/9 and brachinites (Fig. 2). The meteorites lie along a 4.56 Ga initial reference isochron anchored on Solar System initial (SSI) $^{187}Os/^{188}Os$ (Fig. 3), implying derivation from parent bodies (or a single parent body) that experienced comparable melting histories and were formed from similar starting materials. The elevated incompatible element inventory of GRA 06128/9 relative to chondrites implies complementary depleted residues in their parent body. A prediction would be that time-integrated Re/Os would lead to sub-chondritic $^{187}Os/^{188}Os$ in the residue, as is observed for Brachina (Fig. 3); similar incompatible element depletion may also be present for the Rb/Sr, Sm/Nd, Lu/Hf or Pt/Os isotope systems. The ^{53}Mn-^{53}Cr age for Brachina is 4.564 Ga [10], identical within uncertainty, of Pb-Pb, Sm-Nd and Al-Mg ages for GRA 06128/9. Together, geochemical and petrological evidence are consistent with a genetic or process-related relationship between GRA 06128/9 and brachinites.

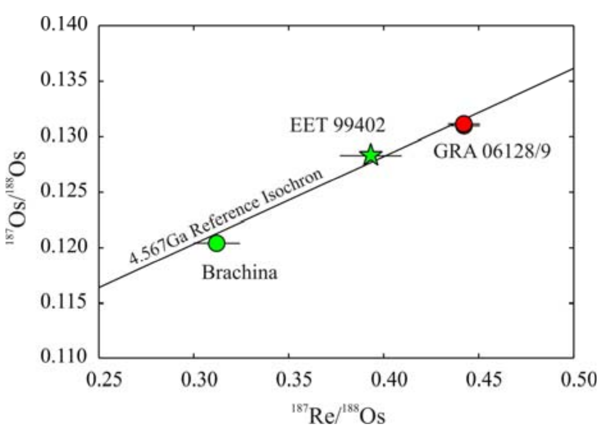

***Figure 3:** ^{187}Re-^{187}Os plot for GRA 06128/9, EET 99402 and Brachina. A 4.56 Ga reference isochron (anchored to SSI) is shown for comparison*

How Extensive Might Evolved Asteroidal Crust Be And Where Should We Look? Because GRA 06128/9 represent a partial melt from portions of a previously undifferentiated asteroid, their volumetric extent will be restricted on any parent body. One scenario is that GRA 06128/9 represent ‘pods’ or ‘dykes’ of evolved material within a heterogeneous crust. An example of a heterogeneous distribution of lithologies is the Caddo County IAB iron meteorite, where silicate inclusions have similar major element compositions to the GRA 06128/9 meteorites [11]. On the other hand, it has been well-demonstrated that the contemporary flux of meteorites is biased and unrepresentative of Solar System materials; this is because of the complex sequence of events required to bring a meteorite from its parent body to Earth. These biases include, but are not limited to, longevity of the parent body in the asteroid belt, location of asteroids near dynamically favorable delivery zones/resonances, impact-excavation and preservation of the meteorite from its parent body and low-velocity collision with Earth. Although these arguments cannot constrain the size of any possible parent body, they do imply that meteorites are likely representive portions of more extensive lithologies. Furthermore, extensive masses of GRA 06128/9-like lithologies might be expected if they are related to brachinites since, like GRA 06128/9 (Fig. 1), up to 25-30% partial melting is required to generate these lithologies [12, 13].

Remote sensing of asteroids shows that, where detected, the preponderance of crust is basaltic. Nevertheless, feldspar-rich crust may not be uncommon in the asteroid belt. Feldspar does not typically have strong adsorptions in the near-infrared, but its relatively high albedo may be a diagnostic feature. However, bright asteroids identified to date (E-type asteroids) include adsorptions indicative of low-Fe pyroxenes [14], inconsistent with the known mineralogy of the GRA 06128/9 meteorites [1]. Based on their possible genetic link, the GRA 06128/9 parent body may be found near possible brachinite parent-bodies [4]. These bodies have been identified among the olivine-rich asteroids based on reflectance spectra that are consistent with the FeO-rich olivine found in brachinites [13]. We are actively examining the spectral properties of GRA 06128/9 as a basis for searching for compositionally similar bodies in the asteroid belt (see [4]).

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