VOLATILE-RICH ASTEROID DIFFERENTIATION AND LINKS BETWEEN FELSIC METEORITES GRAVES NUNATAKS 06128 AND 06129, BRACHINITES AND 'BRACHINITE-LIKE' ACHONDRITES

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Introduction: Antarctic achondrite meteorites Graves Nunataks 06128 and 06129 (GRA 06128/9) represent examples of felsic and highly-sodic differentiation products from volatile-rich asteroidal melting [1,2]. GRA 06128/9 may be process- or genetically-related to brachinites and brachinite-like ultramafic achondrites (similar to brachinites, but with Mg/Fe-rich silicate phases, and which can contain orthopyroxene) based upon similar thermal- and shock-disturbance histories, as well as high modal abundances of olivine (>80%), a range of Fe/Mg silicate phase compositions (olivine Fo_{65-80}), and overlapping $\Delta^{17}O$ values (Fig. 1) [1,3]. The range of $\Delta^{17}O$ values observed in brachinites and brachinite-like achondrites may point to multiple parent bodies (e.g., process-related rocks) or a parent body/bodies with heterogeneous $\Delta^{17}O$ (e.g., genetically-related rocks) [4].

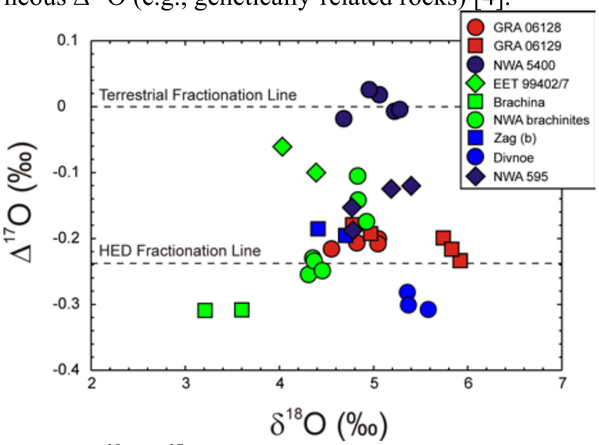

Fig. 1: $\delta^{18}O$-$\Delta^{17}O$ plot for GRA 06128/9, brachinites, and brachinite-like achondrites (Zag (b), Divnoe, NWA 595; NWA 5400). Data from this study, [1,2,4-6].

Volatile-Rich Asteroid Differentiation? We report new major- and trace-element abundances, and highly siderophile element (HSE: Os, Ir, Ru, Pt, Pd, Re) abundance and Re-Os isotope data for GRA 06128/9, 5 brachinites (Brachina, EETA 99402/7, NWA 3151, NWA 4872; NWA 4882) and some brachinite-like achondrites (NWA 5400 + pair; Zag (b)). These data support derivation of GRA 06128/9, brachinites and brachinite-like achondrites from volatile-rich and oxidized 'chondritic' precursor sources within asteroidal parent bodies (Fig. 2). It is possible to generate compositions similar to brachinites and brachinite-like achondrites as residues of moderate degrees (13-30%) of partial melting, coupled with inefficient removal of silica-saturated felsic melts similar to GRA 06128/9 (Fig. 3). A large range in bulk-rock lithophile trace element compositions for brachinites and brachinite-like achondrites can be explained by variable inclusion of minor trapped phosphate and plagioclase in some samples, from inefficient melt segregation, and as partial cumulates for some rocks [7].

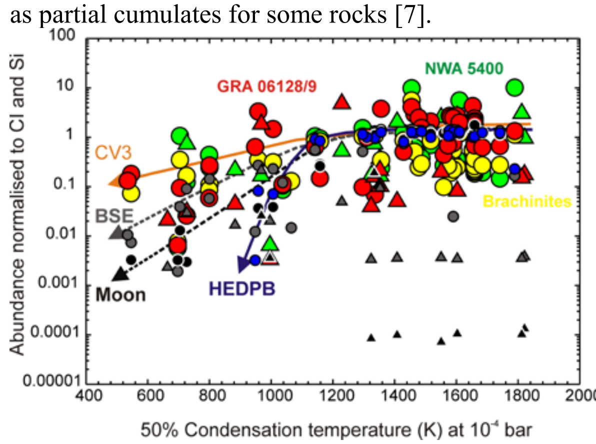

Fig. 2: Condensation temperature versus elemental abundance normalized to CI-chondrites and Si. Condensation temperature, elemental behaviour (L = lithophile [circles]; S/C = siderophile/chalcophile [triangles]), and CV3 trend from [8]. Colours correspond to different parent bodies/meteorite types.

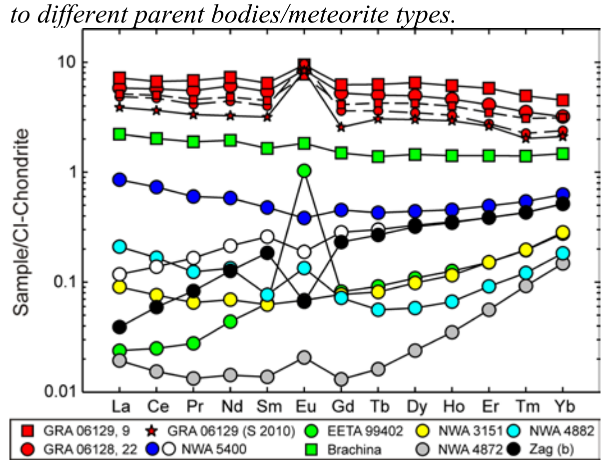

Fig. 3: CI-normalized rare earth element (REE) patterns for GRA 06128/9, brachinites and brachinite-like achondrites. Data from this study, [1], and S 2010 [2].

Siderophile element constraints: Low degrees of partial melting and generation of Fe-Ni-S-bearing melts in the presence of residual metal and sulphide to form the GRA 06128/9 and brachinite meteorites is consistent with HSE abundances within factors of ~2 to 10 × CI-chondrite abundances (Fig. 4), with chondritic $^{187}Os/^{188}Os$ (0.1204-0.1312).

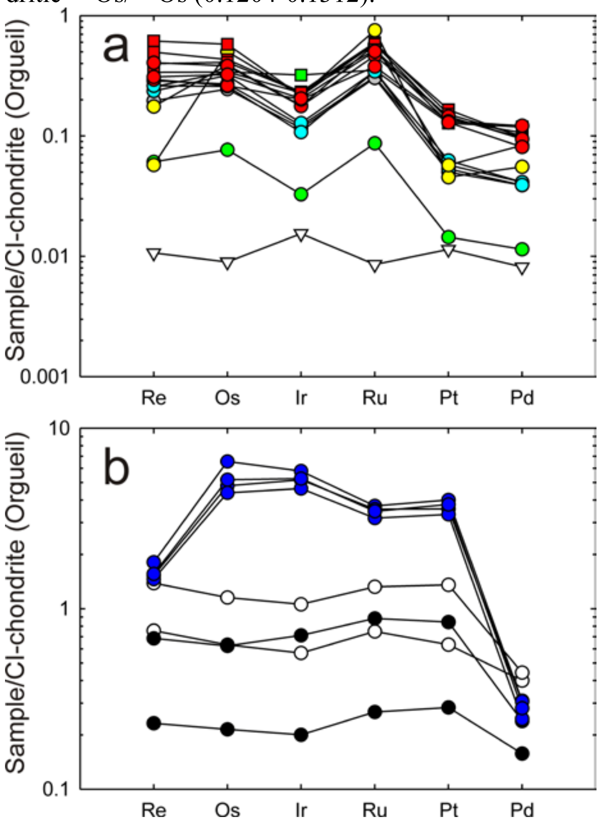

Fig. 4: CI-chondrite normalized whole-rock HSE patterns for (a) GRA 06128/9, brachinites, and (b) brachinite-like achondrites. Symbols as for Fig. 3.

Links between GRA 06128/9 and brachinites? Similar relative and absolute abundances of the HSE in GRA 06128/9 and brachinites, combined with other evidence (petrology, trace-element abundances and O-isotopes), implies process, and possible genetic links for these meteorites. The new HSE data for brachinite-like achondrites (NWA 5400, Zag (b)), in combination with their petrology and geochemistry, may also indicate a process-related link with GRA 06128/9 and brachinites. These new data, in combination with trace element data demonstrate that, during relatively low degree partial melting of a chondritic starting composition, metal-sulphide equilibration and trapping or inefficient segregation of partial melts can lead to complex HSE characteristics in resultant melts and melt residues through variable retention of metals and sulphides in the residue. Such features may be an inherent character of partially melted achondrites (e.g., [1,9]).

Model for volatile-rich asteroid differentiation: We propose a model where an asteroid or asteroids that formed from oxidized chondritic materials underwent low-degree partial melting (13-30%), generating high Fe/Mg and plagioclase-normative (high Al) melts, as well as early Fe-Ni-S melts. These melts were then inefficiently extracted from their sources, generating a range of residue compositions from dominantly olivine-pyroxene residues, to rocks with high proportions of sulphide, metal, plagioclase and phosphate, as well as the possibility of regions of olivine-rich cumulates. Melting was halted, possibly due to the exhaustion of the short-lived radionuclide ^{26}Al associated with felsic melt removal, followed by rapid thermal equilibration (Fig. 5). The new petrological and geochemical observations are consistent with a genetic link between GRA 06128/9 and brachinites. The low Ir/Os and Pt/Os in GRA 06128/9 and brachinites require a complementary metal-rich residue similar to the brachinite-like achondrite NWA 5400.

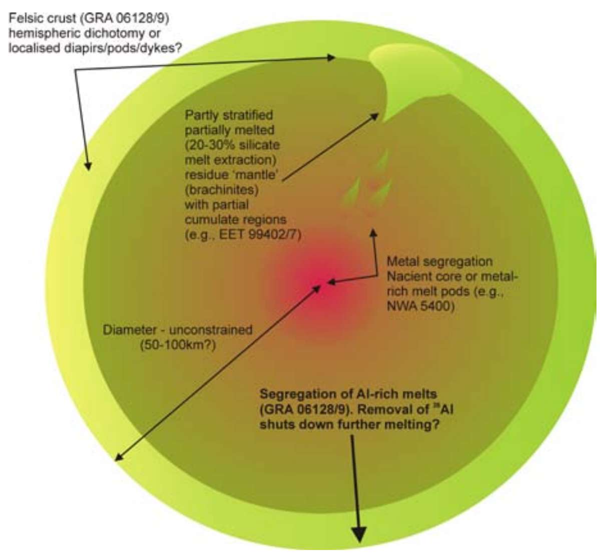

Fig. 5: Schematic diagram of differentiation processes in a hypothetical volatile-rich parent body to the GRA 06128/9, brachinite, or brachinite-like achondrite meteorites.

References: [1] Day et al. (2009) *Nature,* **457,** 179; [2] Shearer et al. (2010) *GCA,* **74**, 1172; [3] Zeigler et al. (2008) *LPSC Abs,* **39**, 2456; [4] Rumble et al. (2008) *LPSC Abs.,* **39**, 1974 [5] Irving et al. (2009) *LPSC Abs.* **40**, 2332. [6] Shukolyukov et al. (2010) *LPSC Abs,* **41**, 1492; [7] Mittlefehldt et al. (2003) *M&PS,* 38, 1601; [8] Lodders (2003) *Astro. J.,* **591**, 1220; [9] Rankenburg et al. (2008) *GCA,* **72**, 4642.