VOLATILE-RICH ASTEROID DIFFERENTIATION AND LINKS BETWEEN FELSIC METEORITES GRAVES NUNATAKS 06128 AND 06129, BRACHINITES AND ‘BRACHINITE-LIKE’ ACHONDrites


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 Fo65-80), 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].

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

**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 \times CI-chondrite abundances (Fig. 4), with chondritic \(^{187}\text{Os}/^{188}\text{Os}\) (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.

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 \(^{26}\text{Al}\) 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: