

R CHONDRITES TO BRACHINITES: INSIGHTS FROM DISCRETE PLATINUM GROUP PHASES AND SULFIDES S. D. Crossley¹, R. D. Ash¹, J. M. Sunshine¹, C. M. Corrigan², T. J. McCoy², ¹ University of Maryland, Department of Geology, College Park, MD (sdcross@umd.edu), 8000 Regents Dr., College Park, MD 20742, ²Smithsonian Institution, Department of Mineral Sciences, Washington, DC 20560.

Overview: The relationship between brachinites and ungrouped brachinite-like achondrites is unclear; differences in HSE abundance can be used for classification, but their fractionation paths are unknown.

R chondrites have been used as analogues for brachinite precursors, but contain abundant sulfides with variable HSE content, no appreciable metal, and discrete Ir, Pt, and Os phases that complicate solid-liquid metal melt modeling.

Hydrothermal alteration in oxidized, primitive parent bodies may produce mineralogies that result in atypical fractionation of HSEs during partial melting, and may be responsible for unusual HSE distributions in related meteorites.

Introduction: Brachinites and ungrouped brachinite-like achondrites are oxidized primitive achondrites characterized by near-chondritic bulk chemistries, igneous textures, and FeO-rich olivine (~Fa₃₀₋₃₅) [1]. Typically, brachinites can be distinguished by a lack of low temperature igneous phases (*i.e.*, phosphates, Fe-Ni metal, and plagioclase) and subchondritic highly siderophile element (HSE) abundances, with depletions in Pt and Ir [2]. The brachinite-like achondrites are a more diverse group characterized by chondritic HSE patterns, a greater abundance of low temperature phases, and are typically less oxidized than brachinites [3]. The exact relationship between the brachinites and brachinite-like achondrites, if any, is unclear, but may include parent body processes during partial melting and/or differences in precursor composition [2].

The oxidized R chondrites have been suggested as analogues to the brachinite and brachinite-like precursor materials [4]. Residues produced in R chondrite melting experiments resemble brachinites in modal mineralogy and major element chemistry [4,5].

Parent body processes have been explored by modeling of HSE partitioning in brachinites, which suggests 13-30% partial melting with complete metal exhaustion and 0% S in the Fe-Ni melt. Ungrouped brachinite-like achondrites may have lost metal that contained as much as 25% S [2]. However, to model the significant depletions in Ir and Pt relative to Os and Ru in brachinites, Os must be twice as compatible as what has been observed in experimental studies [2,6].

Reconciling HSE modeling with experimental results is problematic, as R chondrites are among the most oxidized meteorites, and all Fe is held in sulfides, silicates, and oxides. Consequently, they are devoid of the

Fe-Ni metal that is implicit in HSE modeling. In less oxidized materials, HSEs are hosted primarily in metallic phases; however, discrete HSE phases have been observed in some R chondrites [7,8]. These phases, along with sulfides, are likely the primary hosts for HSEs in R chondrites, which could explain the atypical fractionation of HSEs in brachinites if R chondrites are similar to the brachinite precursors.

In order to assess this mechanism of fractionation, a more thorough examination of HSE distribution in brachinites, brachinite-like achondrites, and R chondrites is required. We have examined the HSE content of individual mineral phases in all three groups to assess how the partitioning and transport of HSEs occurs during the onset of differentiation for oxidized bodies.

Samples: This study includes 5 brachinites (Northwest Africa (NWA) 7297, 7299, and 4882; Eagles Nest; and Ramlat as Sahmah 309), 2 brachinite-like achondrites (Divnoe and Al Huwaysah 010), and 2 R chondrites (NWA 753 and 11304).

Methods: Major element concentrations, EDS spectra, and BSE images were collected at the Smithsonian Institution's Department of Mineral Sciences. Additional major element concentrations were collected at NASA's Johnson Space Center in Houston, TX. *In situ* trace element data were determined via LA-ICP-MS at the University of Maryland's Plasma Laboratory.

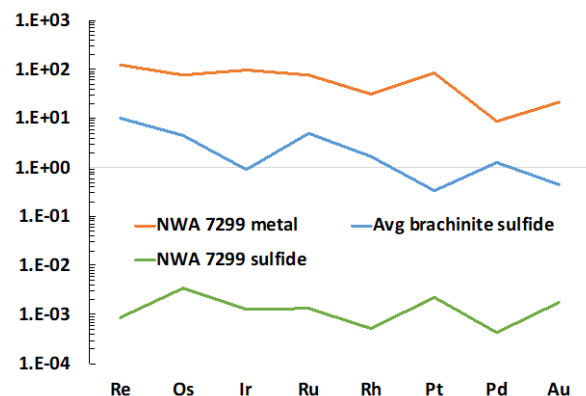


Fig. 1 HSEs in brachinites and brachinite-like metals and sulfides relative to CI chondrites. Brachinite sulfides feature distinct depletions in Ir and Pt. Metals in NWA 7299 contain HSE abundances 5 orders of magnitude greater than in sulfides with no depletions in Ir or Pt. This more chondritic pattern is similar to those of ungrouped brachinite-like achondrites, and may require reclassification for NWA 7299.

Results/Discussion: In brachinites, calculations using measured HSE concentrations and modal abundances show that all HSEs are held in troilite and/or pyrrhotite (Fig. 1), apart from NWA 4882, where it is held in pyrite. Sulfides in metal-bearing brachinite-like achondrites hold negligible HSEs. This is also the case with brachinite NWA 7299, even though it is a classified as a brachinite. Furthermore, the presence of metal and other low-temperature phases is not typical of brachinites, suggesting that NWA 7299 should be reclassified as an ungrouped brachinite-like achondrite.

Both R chondrites in this study contain trace abundances of several types of HSE-rich alloys, including: niggliite (PtSn), irarsite (IrAsS), platarsite (PtAsS), sperrylite (PtAs₂), and pure Os metal. These phases have also been seen in other R chondrites [7,8], and otherwise have been observed exclusively within terrestrial hydrothermal deposits [9]. In NWA 11304, we identified a large 10 μm grain of niggliite (Fig. 2). These discrete HSE phases are most often observed in R chondrite clasts that have experienced some degree of thermal alteration (>R3), and may have been concentrated through hydrothermal processes similar to those that formed amphibole- and biotite-bearing LAP 04840 (R6) [10]. Such atypical distribution of HSEs and concentration into discrete trace mineral phases can also explain the variability in bulk HSEs seen among duplicate analyses of individual R chondrites [11].

Preferential extraction of Pt and Ir-rich alloys prior to, or during, partial melting could explain the anomalous HSE patterns of brachinites. For example, pure HSE phases, such as Os metal, have melting temperatures much higher than Fe-Ni, and would be excluded from early melting in the Fe-Ni-S system, unless entrained within migrating sulfide melt. This would complicate models that assume relatively simple solid/liquid metal HSE partitioning for precursors that did not hold all HSEs in Fe-Ni metal (*e.g.*, ordinary chondrites).

The remainder of HSEs in R chondrites are held in sulfides (pentlandite and pyrrhotite). Pentlandite is the primary host of HSEs. Although HSE patterns are highly variable, most include a strong depletion in Pt. It is not yet clear whether HSE content of sulfides varies with the metamorphic grade of the surrounding clast.

Conclusions: Brachinites and ungrouped brachinite-like achondrites, while similar in silicate mineralogy and major element chemistry, have distinct HSE patterns, suggesting they formed from different precursor materials. In brachinites, all HSEs are held in sulfides, while brachinite-like achondrites hold nearly all HSEs in metal, with little contribution from sulfides.

If brachinite precursors were similar to R chondrites, then HSE fractionation would be complicated by the

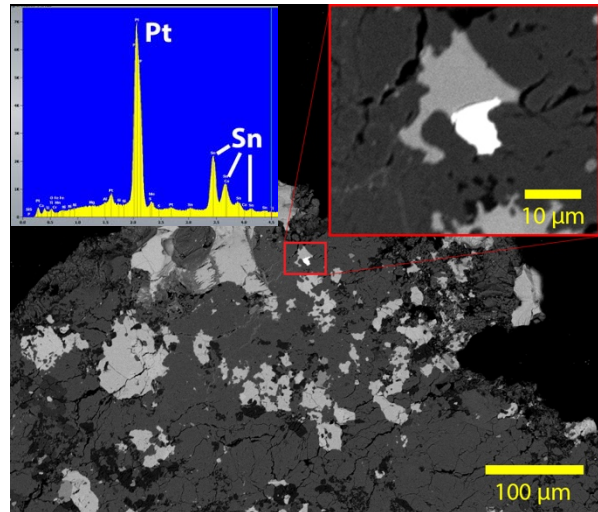


Fig. 2 Niggliite (PtSn, bright white phase, inset) holds the highest concentration of Pt in R-chondrite NWA 11304 by several orders of magnitude. These alloys, most commonly seen as terrestrial hydrothermal alteration products, have been observed exclusively in thermally-altered R chondrite clasts (\geq R4).

presence of discrete HSE phases and HSE-bearing pentlandite. Since ungrouped brachinite-like achondrites retain some Fe-Ni metal and more typical HSE patterns, their precursor(s) were likely less oxidized than R chondrites and distributed HSEs more similarly to the acaulcoite-lodranite clan.

Potential precursors for brachinite-like achondrites may therefore have been more similar to less oxidized, metal-bearing chondrites than to R chondrites. Consequently, the differences in modal mineralogy between the groups may be explained by the lower melting temperatures of oxidized mineral endmembers in brachinite precursors relative to those of the less oxidized ungrouped brachinite-like achondrites.

The presence of discrete HSE phases and phyllosilicates in LAP 04840 also suggest that hydrothermal alteration occurred on the R chondrite parent body, which may be a process that is common during the early stages of differentiation among oxidized parent bodies that accreted more water.

References: [1] Keil K. (2014) *CdE*, 74, 311-329. [2] Day J.M. *et al.* (2012) *GCA*, 81, 94-128. [3] Crossley S.D. *et al.* (2018) *LPSC XLIX* #2540. [4] Gardner-Vandy K.G. (2013) *GCA*, 122, 36-57. [5] Lunning N.G. *et al.* (2017) *GCA*, 214, 73-85. [6] Chabot N.L. & Jones J.H. (2003) *MaPS*, 38, 1425-1436. [7] Bischoff A. *et al.* (1994) *Meteoritics*, 29, 264-274. [8] Schulze H. *et al.* (1994) *Meteoritics*, 29, 275-286. [9] Ramdohr P. (1969) *Ore Minerals & Intergrowths*, 365. [10] McCanta M.C. *et al.* (2008) *GCA*, 72, 5757-5780. [11] van Acken D. *et al.* (2011) *GCA*, 75, 4020-4036.