OLIVINE-DOMINATED ACHONDRITES RECORD MULTIPLE DIFFERENTIATION TRENDS.

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Introduction. The brachinites are a small group of primitive achondrites that are dominated by ~71-96 wt% FeO-rich olivine (Fa_{26-36}) [1]. Most specimens also contain minor pyroxene and plagioclase with trace abundances of chromite, metal, and troilite [2]. These meteorites are usually considered to be residues of limited partial melting (up to 25-30%), though EET 99402 shows possible cumulate texture [2].

Brachinite-like achondrites are broadly similar in modal mineralogy to brachinites. However, they are regarded as ungrouped ultramafic achondrites due to differences in oxygen isotopic compositions and/or olivine compositions that are less ferroan (Figure 1) than is traditionally defined for brachinites [*e.g.*, 1,3].

The relationship between brachinites and the brachinite-like achondrites is unclear. Differences in highly siderophile element (HSE) abundances between brachinites and similar ungrouped achondrites have been observed [4]. This may be indicative of formation on distinct parent bodies that experienced similar processes of concomitant felsic and Fe-Ni-S melt extraction, perhaps at different oxygen and sulfur fugacities (fO_2 and fS_2, respectively) [4]. Therefore, early processes of differentiation may occur via relatively similar pathways for parent bodies that formed from a variety of precursor compositions. Understanding the variability among potential precursor compositions of brachinites and brachinite-like achondrites may therefore clarify processes of core formation.

Chondrites and primitive achondrites can be distinguished by O-isotopes and silicate Fe-Mn-Mg systematics [4]. Samples from evolved parent bodies, like the Martian meteorites or the HEDs, fractionate from a uniform oxygen reservoir and so show mass dependent fractionation along a slope 0.52 line on and oxygen three isotope plot. Related primitive achondrites (*e.g.*, ureilites) from similar precursor materials fall along a linear mixing trend in $\Delta^{17}O$ and Fe/Mg space. In Fe-Mn-Mg systematics, change in slope in Fe/Mg vs Fe/Mn trends can be indicatative of volatility-controlled Mn/Mg fractionation [5].

Bulk Nb/Ta ratios in silicate residues of reduced primitive achondrites were found to vary as a function of oxygen fugacity, interpreted as a result of increasely chalcophile behavior of Nb at more reducing condtions [5]. Subchondritic Nb/Ta ratios in residual materials may therefore record information about oxidation conditions during core formation, providing valuable insight into how precursor composition affects core formation and silicate residue composition.

Samples and Methods: Literature data was gathered for O-isotope, Fe-Mg-Mn, trace element systematics for brachinites (B) and brachinite-like (BL) achondrites [1-4,7-15]. For Ramlat as Sahmah (RaS) 309 (B), Eagles Nest (B), Divnoe (BL), and Al Huwaysah 010 (BL), BSE images and major element data were collected at the Smithsonian Institution's National Museum of Natural History and at NASA's Johnson Space Center. Trace element data was collected via LA-ICP-MS at University of Maryland Plasma Laboratory.

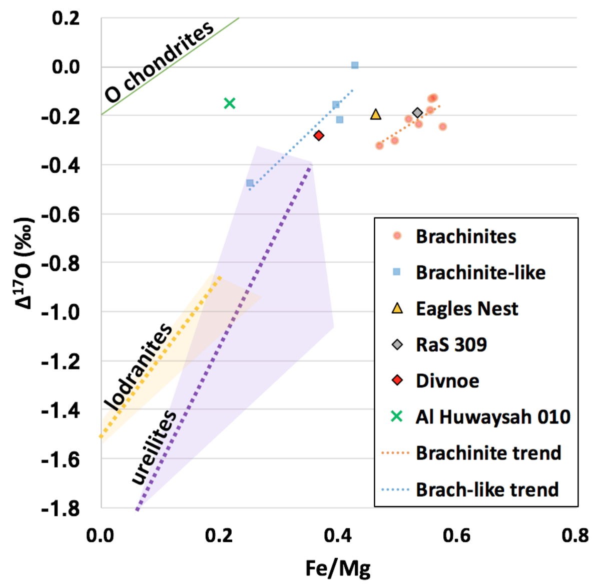

***Figure 1**:* Brachinites and brachinite-like achondrites as a function of $\Delta^{17}O$ and olivine Fe/Mg are separated by Fe/Mg ratios, likely due to differing oxidation states. Data for brachinites and brachinte-like achondrites are from [1-5, 6-14]. Major element data for new samples are indicated by unique symbols.

Results: Figure 1 shows brachinites and brachinite-like achondrites trends as a function of O-isotope and olivine Fe/Mg space with other primitive achondrite for reference. The two groups fall along distinct trends, differing in olivine Fe/Mg while occupying the same $\Delta^{17}O$ space. One sample, Al Huwaysah 010, appears to contain much more reduced olivine, fitting neither trend, and may belong to a separate group.

Figure 2 shows the Fe-Mn-Mg systematics of olivine in both groups. The spread in Mg/Mn (*i.e.*, the change in the slope) records volatile loss of Mn for samples with a greater positive slope. While most samples plot along the same linear trend, the precursors of several olivine-dominated achondrites may have experienced Mn/Mg fractionation during condensation from the solar nebula.

Figure 3 presents Nb/Ta and Zr/Nb data showing bulk abundances of those elements in brachinite and brachinite-like achondrites.

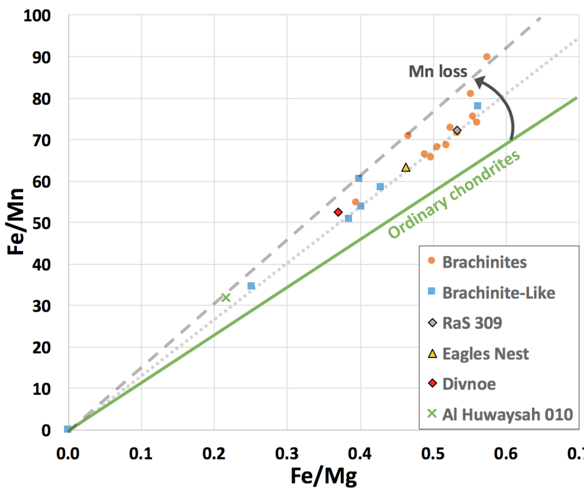

***Figure 2*:** Fe-Mn-Mg systematics in olivine show a spread in Mg/Mn, indicating that the precursors of some materials experienced volatility-driven Mn loss during nebular condensation. Most brachinites and brachinite-like achondrites have a similar Mg/Mn (dotted line), while Al Huwaysah 010, Brachina, NWA 3151 and NWA 4872 show further Mn loss during nebular condensation/evaporation (dashed line).

Discussion: Brachinite and brachinite-like samples in Figure 1 are separated by Fe/Mg in olivine, which likely represents differences in fO_2 conditions. Some samples of both groups are distinct in Mn/Mg ratios (Figure 2), indicating that the precursors of those materials experienced a moderate degree of volatility-driven Mn loss during condensation/evaporation in the solar nebula. While brachinites and similar ungrouped achondrites may have formed in similar temperature environments, they do not appear to be genetically related through trace element systematics (*i.e.*, HSEs) [4], suggesting that they likely formed in at least two distinct parent bodies that experienced core formation under different conditions (*e.g.,* temperature, fO_2, parent body size). It is interesting that brachinites, which are relatively oxidized (~IW), are so depleted in Nb, a characteristic of more reduced achondrites (<IW-2). Generally, more oxidized achondrites (IW-1 and above) retain roughly chondritic Nb/Ta [6]. Lower Nb/Ta ratios in brachinites may reflect selective Nb depletion due to extraction of sulfides and S-rich metals during core formation at fO_2 conditions higher than those reported in [6], evaporation of Nb in the solar nebula at high temperatures, or increasing fO_2 conditions during cooling of the parent bodies from core formation to mineral equilibration.

Future Work: Efforts will continue in analyzing additional brachinites and similar ungrouped achondrites to verify the trends observed to date. The fO_2 of each sample will also be determined and compared to results from trace elements characteristics (*i.e.*, Nb, Ta, and HSEs) to assess whether the differences between the brachinities and brachinites-like meteorites can be explained by oxidation conditions alone.

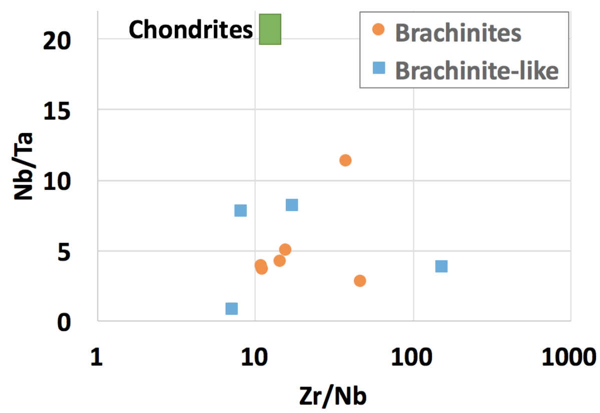

Figure 3: Nb/Ta and Zr/Nb ratios show preferential depletions in Nb, usually characteristic of more reduced assemblages where Nb behaves as a chalcophile and is extracted during core formation [6]. Variation in Zr/Nb correspond to effects of silicate differentiation.

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Acknowledgements: We would like to thank NASA's AS&ASTAR fellowship program for travel and research funding, as well as Northern Arizona University, the Smithsonian Institution's NMNH, and the NHM in Bern, Switzerland, for lending samples for analyses. We also thank Kent Ross for his guidance during analyses, as well as Loan Le for her assistance in operating instruments.