RESIDUAL NATURE OF BRACHINITE-LIKE ACHONDRITES: AN ELECTRON BACKSCATTER DIFFRACTION (EBSD) AND OLIVINE TRACE ELEMENT STUDY. B. H. Gruber[1], R. W. Nicklas[1], J. M. D. Day[1], E. J. Chin[1], M. Ren[2], and R. E. Bernard[3] [1]Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92093, USA. Email: bhgruber@ucsd.edu [2]Department of Geosciences, University of Nevada, Las Vegas, Las Vegas, NV 89154, USA [3]Department of Geology, Amherst College, Amherst, MA 01002

Introduction: Brachinites and Brachinite-like achondrites (BLA) are achondrite meteorite groups characterized by olivine-rich mineralogies (> 90% olivine) and ferroan olivine compositions (Fo_{60-80}). Their olivine-rich nature has often resulted in comparisons with terrestrial peridotites, though their formation mechanism can be contentious [1]. Generally, there are two main mechanisms with which to form brachinites and BLA. They can form as cumulate rocks, through olivine accumulation during fractional crystallization of magmas within a differentiated body, or they are residual rocks, where refractory olivine(±other minor phases) residuum is left over after one or more melting events on a chondritic body during which a silica- and alkali-rich melt is extracted. A cumulate origin would be analogous to dunites and peridotites at the base of large magma chambers whereas a residual origin would be more analogous to refractory terrestrial peridotites.

It has been suggested that brachinite/BLA olivine textures [2] and trace element compositions [3] can distinguish between these formation mechanisms. Electron backscatter diffraction (EBSD) produces quantitative data regarding the orientation and microstructures of minerals within a rock. From terrestrial studies, minerals showing a shape preferred orientation (SPO) would be consistent with a cumulate origin, while those showing a crystallographic preferred orientation (CPO) could indicate a residual, mantle-like environment. However, EBSD data alone can be inconclusive [2], so integration with olivine trace element systematics is optimal. Olivine with relatively high incompatible trace-element (e.g. Al, Ti; [4]) concentrations similar to those of terrestrial lavas would be more akin to the cumulate hypothesis. On the other hand, olivine with depleted trace element concentrations similar to olivine in the terrestrial mantle could be argued as signifying a residual origin. However, melting of chondritic precursors may not yield directly analogous olivine trace element signatures to melting of peridotite, but by considering lithophile trace elements such as Al, meaningful comparisons can be made. We report textural data and olivine compositions for a collection of paired BLA and compare them with terrestrial peridotites.

Methods: Studied samples included: Miller Range (MIL) 090805,8; MIL 090963, 6; MIL 090206, 13; MIL 090340, 11; MIL 090405, 16; MIL 090356, 7; MIL 090405, 7; MIL 090206, 10, all of which are BLA, and the brachinite Allan Hills (ALH) 84025. Olivine and pyroxene major elements were collected using an electron microprobe at *UNLV*. LA-ICP-MS trace element (Na, Al, Ca, Sc, Ti, V, Co, Ni, Ga, Y) analysis on select samples and EBSD were done at UCSD. EBSD data was collected using AZtec software and basic data processing was preformed via MTEX [5].

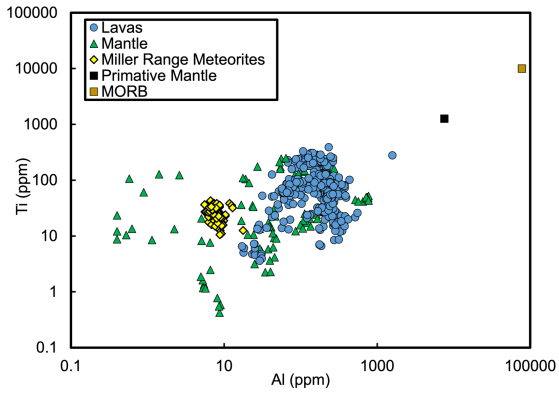

Figure 1:*Olivine Ti vs. Al log-log plot including the MIL meteorites 090963, 090805, 090356, 090340, the Earth's mantle [6], terrestrial lavas [4, 7-10],whole rock primitive mantle [11], and whole rock MORB [12].*

Results: The paired MIL meteorites have similar Fo contents (72-73), typical of BLA [1], while the brachinite (ALH 84025) has slightly lower Fo (65). Using published K_D^{Fe-Mg} values, olivine [13] and clinopyroxene [14] Mg# show that these phases appear to be in or near equilibrium with each other. Olivine trace element systematics for the MIL samples are low in Na (20-148 ppm), Ti (11-59 ppm), and extremely low in Al (5.6-18 ppm) relative to olivine from terrestrial lavas and generally overlap values of the terrestrial mantle **(Fig. 1)**. Olivine Ni (8-147 ppm) and Co (4 – 60 ppm) are also lower than most terrestrial lava olivine.

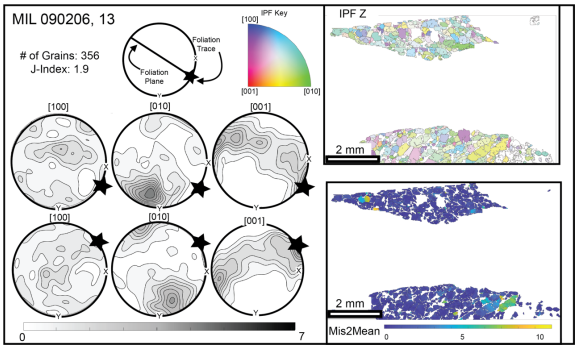

Figure 2*: Olivine fabric 1. Includes a Mis2Mean map, an IPF (Z) map, pole figures, and the J-index [15].*

Phase maps show that the MIL BLA are largely comprised of olivine and only have subordinate clinopyroxene and orthopyroxene, in line with previous studies [3]. IPF maps indicate a preferred mineral alignment in all of the meteorites. Olivine in the MIL BLA is largely tabular, with only minor grain elongation. The Mis2Mean maps show a low concentration of intergranular distortion and an equilibrium texture (smooth, 120° triple junctions) between olivine grains. Textural analysis shows two types of olivine preferred orientation in the BLA. Most (n=7) meteorites olivine pole figures display preferred orientations of the [010] crystallographic axis perpendicular to the inferred foliation/layering plane. Fabric 1 consists of this together with a component of an axial fabric of the [001] within the foliation plane. The brachinite AHN 84025 also shows fabric 1. A second meteorite fabric is present in much lower amounts (n=2), it is similar to Fabric 1, however, the [001] axes make point maxima in the foliation plane as opposed to an axial fabric.

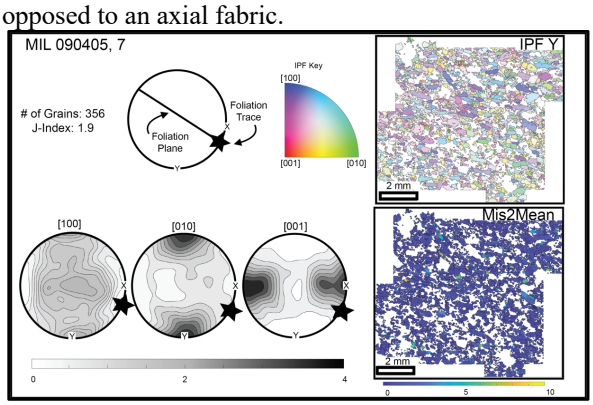

Figure 3: *Olivine fabric 2. Includes a Mis2Mean map, an IPF (Z) map, pole figures, and the J-index [15].*

Discussion: Texturally, MIL BLA show a variety of patterns that are common to peridotites that have undergone solid state deformation on Earth, similar to the findings of [16]. Both fabrics have been reported experimentally in shear environments with the presence of low (4 – 6 %) melt volumes [17]. Fabric 1 can also result from axial compression of olivine crystals [18]. Fabric 2 could also be related toward crystal slip as a result of plastic flow, potentially the [001](010) slip system or "B-Type" fabric [19]. Both of these fabrics are consistent with ductile deformation as opposed to magmatic fabrics owing to passive crystal alignment, which result in shape preferred orientation [20]. Fabrics related to ductile deformation would indicate that the MIL BLA are more similar to residual peridotites as opposed to cumulate peridotites [2]. The residual origin of BLA is corroborated by the olivine trace element data, which show that they are depleted similar to Earth's mantle rather than those crystallized out of lavas, especially in Al concentrations.

The very low concentrations of Ni and Co in brachinite olivine compared to terrestrial peridotite olivine are likely the result of low-pressure metal-silicate equilibration on the brachinite parent body. High pressure core formation, such as that assumed to have occurred on Earth [21], leads to notably less siderophile behavior of Ni and Co. The low Ni and Co of brachinite olivine confirm that metal-silicate equilibration occurred during brachinite genesis and that the brachinite parent body was small (< 100 km). In chondrite partial melting experiments, olivine Fo numbers similar to those measured here result from ~15%-20% melt removal which results in an olivine rich residue [22]. This process of partial melt removal would indicate that the MIL BLA underwent melting processes similar to those in the terrestrial depleted mantle.

These brachinite-like achondrites from the Miller Range are thus residual in nature. This is due to their crystallographic preferred orientation being closely related to deformation along with their geochemistry. This includes the brachinite, ALH-84025, identified as a cumulate by [23], which shows Fabric 1 and is likely formed in a similar way to the MIL BLA. The olivine are not unlike those Earth's terrestrial mantle in that they contain low concentrations of Al and are in major element equilibrium with other minerals.

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