PETROLOGY AND GEOCHEMISTRY OF PAIRED BRACHINITES EET 99402 AND EET 99407. David W. Mittlefehldt¹ and John L. Berkley², ¹NASA/Johnson Space Center, Houston, TX (david.w.mittlefehldt1@jsc.nasa.gov), ²Dept. of Geosciences, SUNY, Fredonia, NY (berkley@fredonia.edu).

Introduction: Primitive achondrites are ultramafic rocks that were heated to higher temperatures than ordinary chondrites, but did not undergo the thorough differentiation that affected the HED parent body [1]. Brachinites form a small, enigmatic group of these primitive achondrites, and we have a poor understanding of their origin. Thus, study of new brachinites can provide significant information on intermediate levels of thermal processing that occurred on asteroids. Here we report preliminary petrologic and geochemical study of the paired brachinites EET 99402 and EET 99407, which we will refer to as EET 9940n.

Petrography and mineral chemistry: EET 99402 and EET 99407 are petrologically identical coarse grained rocks composed of olivine, diopside, plagioclase, spinel and iron sulfides. Olivine generally occurs as equant grains ~0.5-1.5 mm across often with triple junctures. Olivine commonly shows undulose extinction, and planar fractures are present. The average olivine composition is; Fo64.3, CaO – 0.14 wt%, Cr2O3 – 0.02 wt%, molar Fe/Mn - 76.8. Diopside occurs as roughly equant to irregular grains 0.2-0.7 mm across, often interstitial to olivine, and commonly twinned. The average diopside composition is; Wo46.0En43.7Fs10.3, TiO2 – 0.13 wt%, Al2O3 – 1.03 wt%, Cr2O3 – 0.77 wt%, Na2O – 0.36 wt%, molar Fe/Mn - 40.1. Plagioclase occurs as highly irregular interstitial patches 0.2-1.5 mm across. The patches commonly contain vesicles, are composed of mosaics of numerous tiny grains, and often enclose small olivine grains. The average plagioclase composition is; An24.8Ab74.9Or0.3, FeO – 0.17 wt%. Spinel occurs as equant to irregular, interstitial grains ~0.02-0.3 mm across of average composition Sp6.1Hc20.7Mc16.1Cm54.7Uv2.5. Zinc is low (≤0.04 wt%), except in one euhedral grain enclosed in plagioclase with ZnO = 0.40 wt%. Sulfide occurs as minute, generally <10 µm grains, that occur as abundant inclusion curtains in all other phases. Based on the ordinary chondrite shock stage classification [2], the olivine textures imply an estimated shock stage of S3. Weathering appears restricted to minor iron oxide staining along grain boundaries, and suggests a weathering category [3] of W0-W1. However, because these meteorites do not contain metal, and the sulfides are mostly tiny grains enclosed in host mineral grains, this weathering scale devised for ordinary chondrites may not be appropriate.

Geochemistry: We have analyzed three whole rock samples of EET 9940n by INAA. Compared to chondrites, this rock is characterized by depletions in the siderophile elements Ni, Ir and Au, and to lesser extent, Co, and depletion of the chalcophile element Se. Depletion factors relative to CI are; Co – 0.41, Ni – 0.066, Se – 0.074, Ir – 0.066, Au – 0.018. Among brachinites, EET 9940n has the lowest siderophile and chalcophile element contents (Fig. 1).

Figure 1. CI-normalized Se vs. Ni in EET 9940n compared to literature data [4-6] for other brachinites. The horizontal line gives the range in measured Ni in Brachina; there is only a single Se determination.

Figure 2. REE diagram for EET 9940n compared to literature data [4,5,7] for other brachinites, and representative Acapulco- and Lodran-like achondrites [8].

The lithophile transition elements Sc and Cr are at ~1.3-1.4 times CI, while Ca is at ~1 times CI abundance. EET 9940n is extremely depleted in the highly incompatible lithophile elements - the Sm abundance is 0.054 times CI. Europium is at ~0.71 times CI abundances. Among brachinites, EET 9940n has the lowest incompatible lithophile element contents (Fig. 2).

Discussion: Because of the small number of brachinites, the petrogenesis of this group is poorly constrained. The two major competing hypotheses are; (i) metamorphism with or without anatexis (primitive
material or melt residues) [9], or accumulation from a melt (igneous cumulates) [4,6]. The Acapulco- and Lodran-like achondrites form another group of primitive achondrites, and the petrologic and geochemical evidence from them favors an origin via processes (i) above [1]. It is thus instructive to compare the brachinites with the latter group.

Figure 2 shows comparative data for an Acapulco-like achondrite, ALHA81261, and a Lodran-like achondrite, MAC 88177. ALHA81261 has bulk rock lithophile and siderophile element abundances that are essentially chondritic, and exhibit no evidence for planetary-type fractionations [8]. The REE pattern for this rock is very similar to that of Brachina, considered to be an "undepleted" brachinite [9]. Based on lithophile elements, Brachina could be undepleted, metamorphosed chondritic material [5,9]. However, Brachina is depleted in siderophile and chalcophile elements relative to chondritic abundances (Fig. 1). The depletion pattern is not like that expected for either a partial-melting-residue (restite) or a partial melt in the Fe,Ni-FeS system, and suggests rather physical removal of a portion of the metal-sulfide component either by nebular metal-silicate fractionation or a parent body process such as impact melting [10].

The Lodran-like achondrite MAC 88177 has a REE pattern expected of a harzburgitic residue from partial melting at low fO2 – increasing depletion in REE3+ with increasing ionic size and a stronger depletion in Eu2+ due to its greater incompatibility in orthopyroxene. This pattern contrasts sharply with those of EET 9940n and ALH 84025, which have enrichments in Eu relative to REE3+. These patterns, especially that of EET 9940n, are compatible with an igneous cumulate origin. Petrologic and geochemical data favor a cumulate origin for ALH 84025 [4]. The REE pattern in EET 9940n could, however, be consistent with a restite origin if diopside and plagioclase are residual phases, not crystallized trapped liquid. An estimated plagioclase content for EET 9940n based on bulk rock and mineral compositions is ~5 wt%; about half that expected for chondritic silicates. Hence partial melting to remove about half of the potential basaltic component from a primitive brachinite source region is within the realm of possibility. Note that the strong Sm/Eu fractionation implies that there could be very little of a trapped melt component in EET 9940n regardless of its origin.

Mineral composition information favors a cumulate origin for EET 9940n. Figure 3 shows CaO vs. Cr2O3 for the olivines compared to those of L7 chondrite LEW 88663 and numerous Acapulco- and Lodran-like achondrites. Meteorites which are known to have formed by metamorphism of nebular material, or as restites of chondritic material typically have olivines with very low CaO contents, <0.05 wt%. In contrast, EET 9940n olivines contain >0.1 wt% CaO, and the same holds for ALH 84025 and Brachina [4,5]. Although the CaO content of olivine is a function of mg# [see 12], olivines in equilibrated LL chondrites with mg#s approaching that of EET 9940n have CaO <0.06 wt% [13]. Igneous olivines in the PAT 91501 L chondrite impact melt have CaO contents like those of EET 9940n [11]. Thus, we currently believe that EET 9940n is an igneous cumulate, not a restite.

A curious geographical distribution: There are nine named brachinites, all finds, some with unpublished find location. Known or suspected pairing reduces the number of individual falls to ≤7. Two of these falls are from Antarctica, while the remaining ≤5 are from Australia. Either the southern hemisphere is a strange attractor for brachinites, or, more plausibly, many of the Australian brachinites are paired. Detailed study of the group should be undertaken to sort out who’s who, and then evaluate petrologic and geochemical diversity on the brachinite parent body.