**ACHONDRITIC IMPACTOR CLASTS IN NORTHWEST AFRICA 869.**

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**Introduction:** Northwest Africa (NWA) 869 is a L3-6 chondritic regolith breccia comprised of thousands of stones[1]. Regolith breccias offer a unique insight into surface processes such as impact accretion. Signs of impactor material from unknown sources have been previously reported in NWA 869[1]. We report two clasts in NWA 869 that originate from achondritic bodies and relate them to known meteorite groups.

**History of NWA 869 and Justification for use of this Designation:** The type specimen of NWA 869[2] was acquired alongside 257 kg of related material from a single source. The majority of this material went into the Royal Ontario Museum's meteorite collection. These stones all have the "leather-like" fusion crust reported elsewhere[3]. When cut, the stones reveal brecciated matrix material and primarily chondritic clasts. Due to the large number of stones that comprise NWA 869 it can be difficult to verify individual stones. This study involves two stones (M56004 and M53596) in the museum's collection. The exceptional provenance of the samples, their relation to the type specimen and their common properties verify this material as NWA 869.

**Petrography of Clasts:**

*Silica-ilmenite-rich clast*: An achondritic clast measuring ~7 mm (longest dimension) was found in sample M56004 (Fig. 1a,b). It is primarily composed of pyroxene of varying composition (Fig. 2), anorthite (average composition $An_{85}Or_1$), and an unusually large amount of silica ($SiO_2$) and ilmenite (Fig. 1b, Si- and Ti-rich areas). Minor phases include Fe-sulfides, Ca-phosphates and zircon. The pyroxene consists of both augite and pigeonite. Grains of pigeonite with lamellae of augite are common. The grain sizes in the clast are quite variable with pyroxene and anorthite grains as large as ~1 mm at one extreme and broken mixtures of individual micon-sized components at the other extreme. The clast is surrounded by a rim of material containing small pieces of the clast.

*Enstatite-rich clast:* Sample M53596 contains two fragments (2.8 cm and 1.9 cm – longest dimension) of achondritic material that appears to have been a single clast initially (Fig. 1c). The fragments consist of 95% coarse grained (generally 1-5 mm) enstatite ($En_{77}Wo_1$). The remaining 5% consists of high-density phases, primarily chromite ($Cr\#=92$,

$Cr\#=100*Cr/[Cr+Al]$). The chromite is found as both large grains up to 2.5 mm and veins or strings of small crystals (~10 μm in width). Iron sulfide grains, usually <20 μm, are found throughout the clast along with trace amounts of merrillite and chlorapatite.
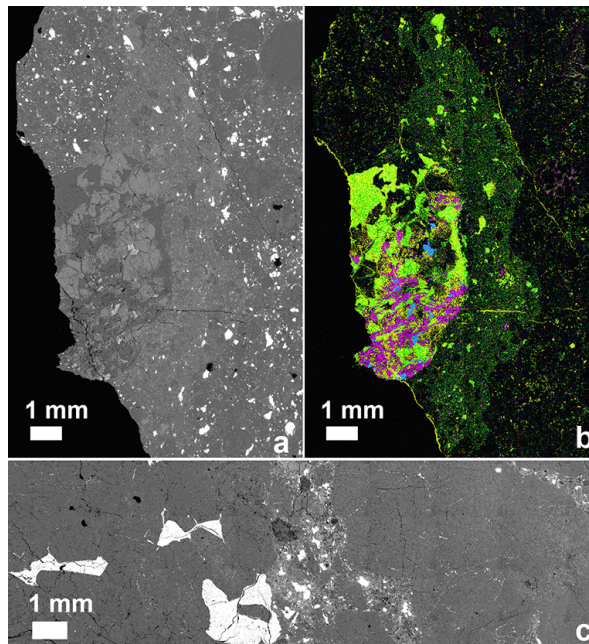


**Figure 1.** a) Backscatter electron (BSE) image showing the silica-ilmenite-rich clast (left) embedded in the L chondrite breccia (right). b) Element map of (a) showing Si (purple), Ti (blue), Al (green) and Ca (yellow). c) BSE image showing the enstatite-rich clast with L chondrite breccia filling a break in the middle. The large white grains are chromite and the remaining clast material is enstatite.
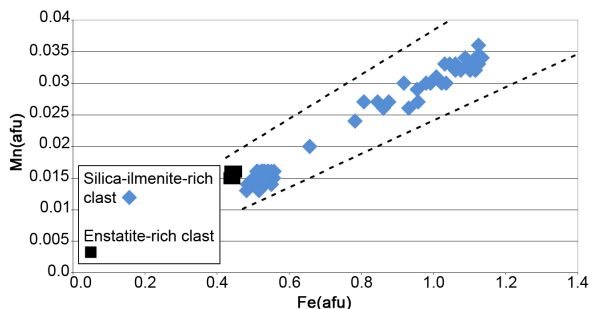


**Figure 2.** Mn versus Fe values for pyroxene in both achondritic clasts. The dotted lines show the range of basaltic eucrite values[4].

**Oxygen Isotopes:** Triple-oxygen isotope data were collected to 1) help establish any relationship between the clasts and known achondrite groups and 2) confirm the L chondrite origin of the bulk rock. Samples were drilled from clasts and matrix exposed in freshly cut slices. Powder samples (2.5-4.0 mg) were compacted into sample holders with a stainless steel rod and oven-dried for 2 days. Dried holders were loaded into a reaction chamber which was heated and evacuated for several hours, repeatedly fluorinated with 25 torr of $BrF_5$, and evacuated, and then fluorinated overnight. Evacuation and fluorination were repeated the next morning until measured room-temperature fluorination products, non-condensable in liquid nitrogen, were reduced to a negligible blank. The samples were then fluorinated by heating with a 30 W SYNRAD $CO_2$ laser in an atmosphere of 30 torr $BrF_5$. The following values were obtained in per mil.

*M56004 Silica-ilmenite-rich clast:* $\delta^{17}O$ = 1.63, 1.56; $\delta^{18}O$ = 3.55, 3.46; $\Delta^{17}O$ = -0.240, -0.258; **rim:** $\delta^{17}O$ = 2.60; $\delta^{18}O$ = 4.31; $\Delta^{17}O$ = 0.326; nearby **L chondrite clast:** $\delta^{17}O$ = 3.76; $\delta^{18}O$ = 5.28; $\Delta^{17}O$ = 0.982; **L chondrite matrix:** $\delta^{17}O$ = 3.58, 3.71; $\delta^{18}O$ = 5.02, 5.01; $\Delta^{17}O$ = 0.941, 1.079.

*M53596 Enstatite-rich clast:* $\delta^{17}O$ = 2.03, 1.99, 1.68, 2.30; $\delta^{18}O$ = 3.86, 3.80, 3.25, 3.96; $\Delta^{17}O$ = 0.003, -0.015, -0.032, 0.217; **L chondrite matrix:** $\delta^{17}O$ = 3.68, 3.69; $\delta^{18}O$ = 5.14, 4.88; $\Delta^{17}O$ = 0.974, 1.130.
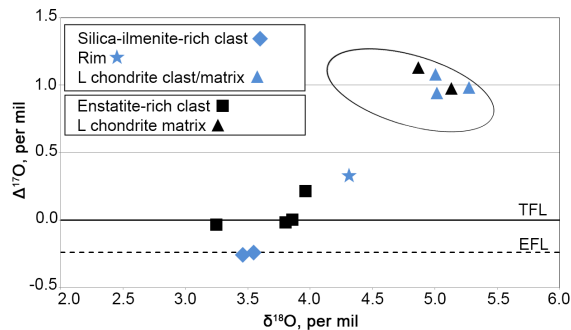


**Figure 3.** Oxygen isotope plot for the two achondritic clasts and surrounding material. The terrestrial fractionation line (TFL) is marked along with the eucrite fractionation line (EFL)[5]. The circled area represents the range of L chondrites[6].

**Discussion:**

*Silica-ilmenite-rich clast*: Pyroxene compositions are consistent with a howardite-eucrite-diogenite (HED) parent body origin (Fig. 2) and oxygen isotope values confirm this idea (Fig. 3). The mineralogical composition of the clast suggests it is best described as anomalous eucritic material. Past studies have found basaltic eucrites with silica-rich regions[e.g. 4]. The clast rim has oxygen isotope values consistent with mixing of L chondrite material with the achondritic clast material. This impact generated mixture provides a unique opportunity to study impact accretion and will be the focus of further study.

*Enstatite-rich clast:* The oxygen isotope composition of this clast falls on the TFL (Fig. 3), with the exception of one data point that appears to contain L chondrite contamination. Future oxygen analyses of acid-washed grains are planned to rule out terrestrial contamination. The enstatite Fe-Mn concentrations are not consistent with terrestrial or lunar samples analyzed in past studies[e.g. 7]. The mineralogy, geochemistry and oxygen isotope analyses do not specifically point to any known achondritic group. The enstatite-dominated mineralogy and oxygen isotope values are consistent with aubrites or enstatite achondrites; however, the relatively high Fe-content of the enstatite and the significant amount of chromite present are inconsistent with this association. "Brachinite-like" meteorites[e.g. 8] also fall on TFL; however, these meteorites have an olivine-dominant mineralogy and large enstatite-rich regions have not been observed. Trace element analyses will be carried out to help determine any association with these or other known meteorite groups.

*Chondritic clast and matrix:* The oxygen isotope values for a chondritic clast and matrix material from the host rock are consistent with a L chondrite parent body. Future work on this material should be carried out to determine terrestrial ages and/or noble gas concentrations in order to compare these stones with materials being studied by other research groups[e.g. 9].

**Conclusions:** Regolith breccias provide a unique opportunity to study asteroid surface processes. Two achondritic clasts in NWA 869 have been identified as impactor material - one coming from the HED parent body and the other coming from an unidentified source. The large amount of NWA 869 material available for study is an untapped source of a potentially diverse range of meteoritic materials. Our work demonstrates that these stones contain material that is unlike anything reported previously.

**References:** [1] Metzler K. et al. (2011) *MAPS, 46(5)*, 652-680. [2] Connelly H. C. et al. (2006) *MAPS, 41(9)*, 1386-1387. [3] Metzler K. et al. (2008) *LPS XXXIX*, Abstract #1120. [4] Mayne R. G. et al. (2009) *GCA, 73*, 794-819. [5] Greenwood R. C. et al. (2005) *Nature 435*, 916-918. [6] Clayton R. N. et al. (1991) *GCA, 55*, 2317-2337. [7] Karner J. et al. (2006) *American Min., 91*, 1574-1582. [8] Day J. M. D. (2011) *GCA, 81*, 94-128. [9] Welten K. et al. (2011) *MAPS, 46(7)*, 970-988.