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NWA 4477: A UNIQUE IMPACT MELT BRECCIA. D. L. Schrader¹, D. S. Lauretta¹, H. C. Connolly Jr.^{1,2,3}, T. J. McCoy⁴, R. C. Greenwood⁵, and I. A. Franchi⁵. ¹University of Arizona, Lunar and Planetary Laboratory (LPL), Tucson, AZ 85721, USA, (schrader@lpl.arizona.edu), ²Dept. Physical Sciences, Kingsborough Community College of the City University of New York, 2001 Oriental Blvd., Brooklyn N.Y. 100235, USA, and the Dept. of Earth and Environmental Sciences, The Graduate Center of CUNY, ³Dept. Earth and Planetary Sciences, AMNH Central Park West, New York, N.Y. 110024, USA, ⁴Dept. of Mineral Science, National Museum of Natural History, Smithsonian Institution, Washington DC 20560-0119, ⁵PSSRI, The Open University, Milton Keynes MK7 6AA, UK.

Introduction: NWA 4477 is a highly brecciated type L3-7 chondrite. It therefore offers a unique insight into the history of the L-chondrite parent body. Of the ordinary chondrites, the L class has the lowest number of brecciated members at ~10% [1], some of which are impact melts. A possible relationship between FeO-rich primitive achondrites to L7 and LL7s as potential precursors has been suggested [2]. The designation of type 7 material [3,4], thermally altered equilibrated chondritic material lacking chondrules, also loosely describes primitive achondrites. Primitive achondrite's precursors are thought to be chondritic material that underwent partial melting and crystallization without melt migration [4,5].

This study of NWA 4477 aims to (1) determine the relationship of the type 7 clast to its chondritic host and to primitive achondrites, (2) determine its formation mechanism, and (3) understand the melting of the L-chondrite parent body.

Analytical Procedure: We examined one thin section from the L3-7 genomic breccia (S3 W1) NWA 4477 (Fig. 1). Quantitative analyses were performed on the Cameca SX-50 EMP at LPL using an accelerating voltage of 15 kV and a beam current of 20 nA. The concentrations of Na, K, Si, Mg, Al, Ca, Mn, Fe, Cr, Ti, and Ni were determined for silicate analyses, and Fe, Ni, Mn, S, Cr, P, Co, Ti and Cu were determined for metal and sulfide analyses. X-ray maps were obtained on the EMP. Volume percents (vol.%) were determined using pixel counting in Adobe Photoshop®. Bulk oxygen isotopic analysis on the L3-6 portion and the L7 portion (henceforth termed coarse-grained clast) were undertaken by infrared laser fluorination [6].

Results: In cross-section, it is apparent that a coarse-grained clast composes ~20% of the thin section, and contains no chondrules. The remaining portions contain abundant chondrules and distinct chondrule bearing clasts. The boundary between these two lithologies is distinct, and shows no evidence that the major clast experienced significant thermal processing. There are thin melt veins bearing metal spherules which cross-cut the sample, one of which is continuous across the chondrule-bearing portion and the coarse-grained clast. Overall, the meteorite contains

olivine, pyroxene, plagioclase, kamacite, taenite, troilite, and Ca-phosphate.

Chondritic Host. The chondritic portion of this meteorite can be separated into at least four clasts, and two fine grained, chondrule-free, optically dark inclusions which are distinct from the matrix. Chondrule types consist of PO, POP, RP, C, and BO, with apparent diameters ranging from 0.45-1.30 mm. There are sharply defined and relict chondrules present. The abundance of opaques (metal, sulfide, and chromite) in this portion is ~3.6 vol.%. Overall, the composition is $Fa_{1.03-26.95}$, low-Ca pyroxene $Fs_{2.07-21.06}$ and $Wo_{0.03-2.78}$, high-Ca pyroxene $Fs_{3.49-23.78}$ and $Wo_{4.19-42.02}$, with kamacite (Ni wt% 5.41 ± 2.01 and Co wt% 0.72 ± 0.10). It also contains anorthoclase ($An_{28.64}$, $Or_{17.99}$, and $Ab_{53.37}$), and oligoclase ($An_{13.34}$, $Or_{5.62}$, and $Ab_{81.03}$). Bulk O-isotopic composition is $\delta^{17}O\text{‰}=3.52$, $\delta^{18}O\text{‰}=4.64$, and $\Delta^{17}O\text{‰}=1.11$.

Coarse-grained Clast. In hand sample, this clast is highly friable. It is dominated by euhedral and subhedral normally zoned olivine grains (e.g. core to rim $Fa_{21.1-31.8}$) which range in apparent diameter from 0.05-2.63 mm, set in a fine grained matrix of Al-rich feldspar, compositionally closest to andesine (Fig. 2). Euhedral, subhedral, and skeletal grains of pyroxene are also present. Some olivine and pyroxene grains are found at triple junctions. The andesine matrix is approximately 15.1 vol.% of the clast. Small rounded and elongated Ni-poor troilite, which contain rounded Ni-poor kamacite (relative to chondritic host) grains, are present in the andesine matrix (Fig. 2). The abundance of opaques in this clast is ~0.1 vol.%. Its composition is $Fa_{13.35-36.35}$, low-Ca pyroxene $Fs_{19.03-24.24}$ and $Wo_{1.01-4.77}$, high-Ca pyroxene $Fs_{19.13-35.20}$ and $Wo_{10.28-47.91}$, with kamacite (Ni wt% 3.67 ± 1.52 and Co wt% 0.77 ± 0.20), with andesine ($An_{31.55-35.03}$, $Or_{1.16-3.27}$, and $Ab_{63.33-65.18}$). Bulk O-isotopic composition is $\delta^{17}O\text{‰}=3.51$, $\delta^{18}O\text{‰}=4.61$, and $\Delta^{17}O\text{‰}=1.11$.

Discussion: The bulk oxygen isotopes of the chondritic host and the coarse-grained clast are essentially identical, and plot in the center of the L-chondrite field on the oxygen three isotope plot. According to the classification scheme of [7], the clasts in the chondritic host represent types 3, 4, 5 and 6; which all match the L-chondrites. The Co wt% in kamacite and the average composition of the olivine and pyroxene in the coarse-

grained clast are all in the range for L-chondrites. The boundary between these two distinct lithologies lacks glass, whereas a boundary of glass would suggest an impact melt. The opaque abundance of the L3-6 region is also in agreement with the average value for L-chondrites of ~4 vol.% [4]. In contrast, the opaque abundance of the coarse-grained clast is only ~0.1 vol.%.

Impact melts are depleted in metal and sulfide and show quenched textures [8,9]. The coarse-grained clast's depletion in opaques with respect to the L3-6 portion is consistent with an impact melt. However, unlike impact melt breccias this clast does not have a quenched texture. In contrast, its large grain size suggests it was not completely melted and retained numerous nucleation sites.

Relative to the L3-6 portion, the silicates of the coarse-grained clasts are more FeO-rich; likely the result of the melt being oxidizing, driving Fe into the silicates. However, the majority of metal and sulfide was likely lost as an immiscible melt. The clast is also depleted in volatiles relative to the L3-6, namely S and P. The zoned nature of the clast's silicates suggest it cooled before it equilibrated. The unequilibrated nature of the coarse-grained clast shows that it is not a type 7 clast, as further heating of equilibrated type 6 material would not result in unequilibrated material [4]. There are also unequilibrated silicates near the coarse-grained clast, therefore showing no evidence for thermal processes of the major clast near the boundary.

The coarse-grained clast is likely the result of impact melting of L-chondrite material. It is important to note, that if this clast had been discovered separately from the chondrule bearing portion, using only optical microscopy and EMPA, it would likely be classified as an ungrouped primitive achondrite.

Conclusions: Relative to the L-chondrite, the coarse-grained clast is depleted in metal and sulfide; the FeO content of the silicates is enriched due to oxidizing conditions; the Ni content within the metal is depleted; it lacks Ca-phosphates and is subsequently depleted in P; its plagioclase is depleted in K but enriched in Ca and Al; it lacks chondrules; and contains olivine and pyroxene crystals which are on the order of chondrule diameters.

The coarse-grained clast in NWA 4477 is compositionally inconsistent with the primitive achondrites and type 7 chondrites, and is most likely a recrystallized impact melt of L-chondrite material. The large euhedral crystals and unequilibrated silicates suggest the coarse-grained clast was incompletely melted, retaining numerous nucleation sites. The depletion in volatile and incompatible elements suggests it underwent

fractional crystallization. The lack of glass along the boundary, and lack of thermal processes near the boundary in the chondrite suggests this clast was melted and cooled in another location, and subsequent impacts placed it in its current setting. Therefore, this meteorite is best classified as an L3-6 genomic breccia, which contains an impact melt clast.

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Figure 1. Plane light image of the thin section, shows distinct lithologies of the L3-6 host and the coarse-grained clast (lower right). Note the 5.00 mm scale bar.

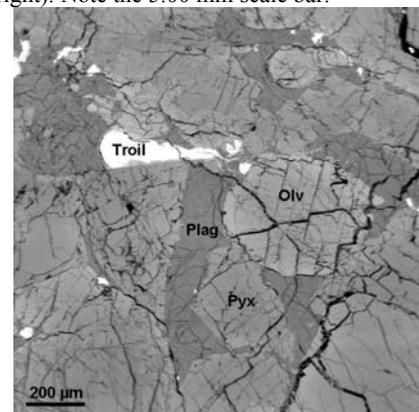


Figure 2. BSE of an area in the coarse-grained clast. Troil=troilite, Olv=olivine, Pyx=pyroxene, Plag=plagioclase. Fractures due to friable nature of sample during preparation.