

INITIAL DESCRIPTION OF AN IMPACT MELT CLAST IN LL3 CHONDRITE NORTHWEST AFRICA

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Introduction: The physical evolution of asteroids is driven by multiple episodes of collisional processes, such as excavation of materials, mixing, and reaccretion [e.g., 1]. Brecciated meteorites and meteorites containing xenolithic clasts provide evidence of these dynamic impact-dominated histories. Though the number of meteorites containing foreign clasts is not well constrained, brecciation is common among many groups of meteorites (e.g., CI, CM, and CV carbonaceous chondrites, aubrites, mesosiderites, and HEDs) [1]. In fact, a recent study by [2] suggests that 27% of ordinary chondrites - the largest group of meteorites - are breccias.

Recently, we purchased a 68.2 g slice of LL chondrite Northwest Africa (NWA) 10598, which contains a single angular clast (Fig. 1). This 65.4 mm² clast was covered by a coating of white powder, which is thought to be a product of terrestrial weathering. The boundary between the clast and the host meteorite is very sharp, and clast is texturally distinct from the host (i.e., chondrules are absent). This suggests that the clast and the host meteorite formed under different conditions and possibly represent material from two parent asteroids.

Here, we characterize the texture, mineralogy, and bulk composition of this clast in an effort to identify its source material and to better understand the physical evolution of its parent body.



Fig 1. Slice of NWA 10598 showing the angular clast with white surficial coating.

Host Meteorite: NWA 10598 is an LL ordinary chondrite consisting of large (650±450 µm) porphyritic olivine and pyroxene chondrules in an opaque matrix

[3]. NWA 10598 is classified as petrologic type 3.15 based on the average abundances and standard deviations of fayalite (Fa_{17±9.4}) and Cr₂O₃ (0.22±0.08 wt%) in chondrule olivine [3].

Clast Description: The clast has a microporphyritic texture, with subhedral-euhedral phenocrysts of zoned olivine (50–400 µm) in a mesostasis of glass and quench crystallites (Fig. 2). Smaller, unzoned olivine grains (5–30 µm), which are typically more anhedral than the zoned olivine, are dispersed throughout the mesostasis. In addition to olivine, several large FeNiS globules are also present in the mesostasis. The FeNiS globules, which are concentrated in the interior of the clast, are spherical to irregularly-shaped and range in size from ~150–700 µm (Fig. 3). No vesicles were observed. Extensive fracturing is present throughout the clast, but is not observed in the host meteorite. Olivine grains along the boundary of the clast and host meteorite are broken, suggesting that the clast is fragmental.

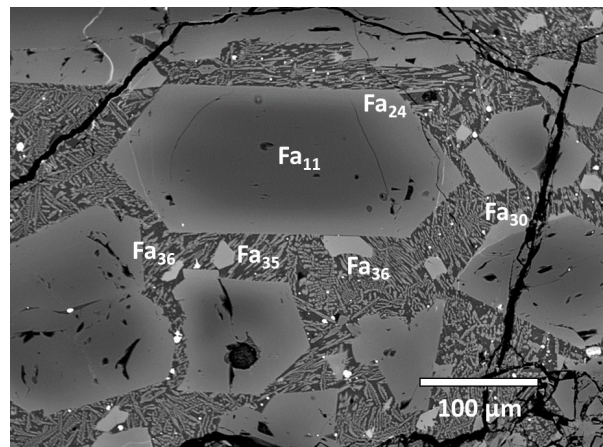


Fig. 2. Backscattered electron (BSE) image illustrating the microporphyritic texture of the clast. Here, zoned olivine microphenocrysts are surrounded by small Fe-rich olivine grains in a mesostasis of glass and pyroxene crystallites. Large fractures cross-cut the phenocrysts and mesostasis.

The majority of olivine microphenocrysts are compositionally zoned, with Mg-rich cores (Fa₁₀₋₁₄) surrounded by Fe-rich rims (Fa₁₉₋₂₇). The smaller, unzoned olivine grains are more Fe-rich (Fa₂₉₋₅₃) than the zoned olivine phenocrysts. The average Fe/Mn ratios of eight zoned olivine microphenocrysts range from 38 to 49. However, molar Fe/Mn ratios of the zoned olivine vary widely within a single grain (i.e., Fe/Mn = 33-91).

Fe/Mn ratios of the small, unzoned olivine phenocrysts range from 37 to 59, with an average of 44 ($n = 18$).

The mesostasis consists of glass with crystallites of pyroxene ($\text{En}_{51}\text{Fs}_{32}\text{Wo}_{17}$). The average bulk composition of the mesostasis (glass plus crystallites) (in wt%) is: $\text{SiO}_2 = 60.8$, $\text{MgO} = 6.0$, $\text{Na}_2\text{O} = 4.8$, $\text{Al}_2\text{O}_3 = 8.4$, $\text{P}_2\text{O}_5 = 0.65$, $\text{CaO} = 6.2$, $\text{TiO}_2 = 0.35$, $\text{K}_2\text{O} = 0.86$, $\text{MnO} = 0.36$, $\text{FeO} = 11.2$, and $\text{Cr}_2\text{O}_3 = 0.46$. The mesostasis has a CIPW normative composition that would crystallize olivine, hypersthene, plagioclase, and diopside.

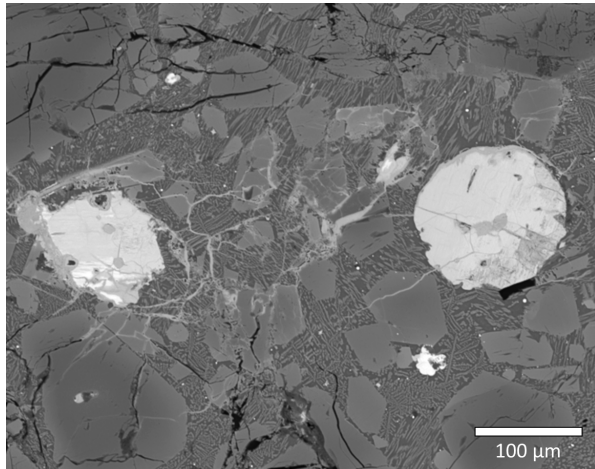


Fig 3. BSE image highlighting two of the smaller FeNiS globules (~100 μm diameter).

Modal abundances of the clast - estimated by point counting backscattered electron (BSE) images - are 66% olivine, 31% mesostasis, and 3% FeNiS. Using modal recombination we calculated the bulk composition of the clast. Average elemental abundance wt.% ratios are: $\text{Mg/Si} = 0.923$, $\text{Al/Si} = 0.067$, $\text{Ca/Si} = 0.068$, $\text{Na/Ca} = 0.784$, and $\text{Mn/Al} = 0.171$.

Clast Provenance: The zoned olivine, glassy mesostasis, and FeNiS globules are characteristic features of impact melts [e.g., 2,4]. Impact melts form as the result of partial or complete melting during high-P and high-T impact events [e.g., 1,5,6]. During melting, sulfides and metal separate immiscibly from the silicate portion of the sample [7,8]. As a result, the bulk composition of a melt clast is analogous to the silicate portion of its source [4]. The absence of unmelted fragments in the clast examined here suggests that it experienced complete melting. However, the presence of mesostasis indicates that the melt was quenched before it fully crystallized.

To assess possible precursors, we compared abundance ratios of the clast to bulk compositions of more than 250 meteorites analyzed by [9,10]. Abundance ratios of the clast, particularly low Al/Si, low Ca/Al, and high Mn/Al, are consistent with an ordinary chondrite precursor.

The composition of olivine in the clast is also comparable to the ordinary chondrites. Olivine in the zoned phenocrysts is similar (in Fa content and Fe/Mn ratios) to Type II (high-FeO) porphyritic olivine chondrules (Fa_{10-25} ; $\text{Fe/Mn} = 26-49$) the unequilibrated ordinary chondrites [e.g., 11-14]. The average composition and standard deviation of fayalite ($\text{Fa}_{15.8 \pm 8}$ and 0.28 ± 0.09 wt% Cr_2O_3) suggest that the clast experienced very mild metamorphism (petrologic type 3.15), similar to the host [14].

Though the average composition of olivine in the clast is more Mg-rich (Fa_{15}) than olivine in the equilibrated H chondrites (Fa_{16-20}) [12], the composition and zoning of individual olivine phenocrysts in the melt clast is similar to impact melt material in H chondrites NWA 2443 (H3-6) and Dar Al Gani 167 (H5-6), which both contain olivine phenocrysts with Mg-rich cores (~ Fa_{7-12}) surrounded by Fe-rich rims [2]. Based on these similarities, we suggest that the source of the impact melt clast in NWA 10598 is an H chondrite.

Parent Body Evolution: The melt clast in NWA 10598 was originally part of a larger impact melt on the H chondrite parent asteroid, which experienced complete melting but quenched before it fully crystallized. During a secondary impact event, the clast was fragmented from this melt region and ejected from the parent body. Subsequently, the clast reaccreted onto the surface of the LL chondrite parent asteroid, where it experienced minor thermal metamorphism.

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