REGOLITH PROCESSING ON L CHONDRITE BODIES AS WITNESSED BY NWA 869

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Rationale: Of all chondritic meteorites, the ~seven tonnes of L3-6 NWA 869 [1,2] represents the largest single strewnfield sample of a near-surface regolith breccia from the early solar system [3,4]. The wide variety of pieces from NWA 869 offer an unusual opportunity to examine an early asteroidal regolith at something like "outcrop scale," providing greater context for other observations. NWA 869 at the Royal Ontario Museum (ROM) consists of more than 300 individual pieces acquired from one source, ranging in mass from a few grams to 14 kg, for a total of 257 kg [5]. Wire saw slicing of 25 individual meteorites has revealed more than 7,500 cm^2 of NWA 869 breccia surface area for examination and subsampling. Here we report on observed matrix and clast textural relationships in four ROM samples M57458 - M57461 from two individuals, following the NWA 869 work of Metzler et al [2] and Hyde et al [5] on other individuals, and discuss possible constraints on early solar system regolith processing on this L chondrite parent body.

Methods: Following inspection of cut slabs and ends from NWA 869 individuals, polished thin sections were prepared of regions exhibiting unusual clasts and notable clast-matrix relationships. Electron probe microanalysis (EPMA) of silicates, sulphides and oxides was conducted at Queen's University using a JEOL JXA-8230 equipped with five wavelength dispersive spectrometers (WDS). Analyses used a 15 kV accelerating voltage and a 20 nA beam current. *In situ* micro X-ray diffraction for mineral identification and textural analysis [6] was performed using a Bruker D8 Discover diffractometer, operating with Co Kα radiation (λ = 1.78897 Å) at 35 kV and 45 mA and a nominal incident beam diameter of 300 μm [6].

Observations: NWA 869 consists entirely of lithified clastic material, including a highly comminuted crystalline matrix. Examination of >3,500 cm^2 of cut faces in this work shows that matrix (inclusive of clasts <3 mm) occupies ~60% of the meteorite. Most visible clasts at hand sample and thin section scale are of L 5-6 chondrite [1,2] for ~35%, but other, more exotic clasts are present, including ubiquitous grey impact melt rocks [2], rare silica-bearing clasts [2,5] and clasts representing achondritic impactor material [5].

Matrix: Clasts and other matrix constituents such as chondrules and single crystals are typically enshrouded by a fine, dark 1-3 μm mantle of crystalline debris (Fig 1). Most notably, disseminated sulphide dominates ~2:1 over FeNi metal blebs as the dense, metal rich phase in the matix, whereas they are subequal in L chondrite clasts. The sulphide tends to lie interstitially between clastic fragments and is in places gathered as ~ 5 mm blebs. As noted previously [2], olivine in the matrix has variable composition (here found to be $Fa_{24.65\pm0.78}$; n=7), and zoned silicates are observed in backscattered electron (BSE) images, indicating that the NWA 869 regolith breccia has -in bulk- retained low petrographic type 3 conditions.

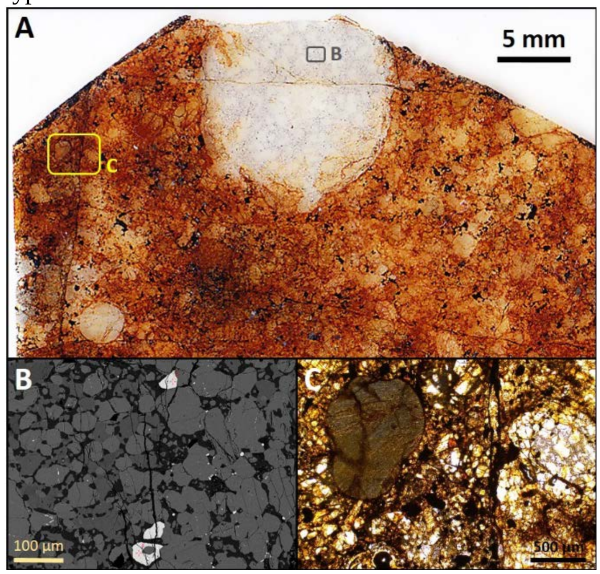

Figure 1: (A) Thin section image of NWA 869 fragment M57458, dominated by a shock-veined L5 clast which itself contains a 12 mm white ophimottled clast; (B) BSE image of white clast subhedral olivine, Ca-rich pyroxene and euhedral chromite in a feldspar matrix; (C) PPL image of contact between L5 clast (right 1/3 of image) and breccia matrix (left) in which all components have characteristic dark mantles.

White igneous-textured clast: Sample M57458 contains a 12 mm diameter ophimottled clast with subhedral olivine and Ca-rich pyroxene enclosed in a feldspathic matrix, in places poikilitically enclosed by the feldspar or Ca-poor pyroxene (Fig. 1B). Sulphide is absent and FeNi metal occurs sparsely; euhedral chromite is the principal opaque phase, occurring as ~30 μm grains and along planes in olivine as fine 1 μm inclusions. The white clast itself lies within a L5 clast which exhibits shock veins and chromite inclusions within olivine; the white clast does not appear to be a chondrule, having an irregular, embayed contact with the host L5 clast. Despite the evidence for shock metamorphism, petrographic [7] and *in situ* micro-XRD [6] observations indicate shock S2, suggesting that the L5 clast has experienced post-shock annealing prior to its inclusion in the NWA 869 breccia.

Spinifex-textured melt clasts: Samples M57459-60 from the same individual contain angular grey spinifex-textured ~cm clasts. One clast contains euhedral olivine with ubiquitous strings of variable composition FeNi metal inclusions, set in a fine groundmass of feldspar and skeletal olivine. Olivine ($Fa_{24.33\pm0.34}$; n=9) is indistinguishable from that of the host L chondrite. The clast in M57460 contains zoned olivine (cores $Fa_{10.32\pm0.36}$; n=5; rims $Fa_{29.27\pm3.43}$; n=5) set in a fine matrix of skeletal olivine, feldspar and blebs of sulphide + FeNi metal + chromite exhibiting immiscibility textures (Fig 2). Both appear to be impact melt clasts [2], likely derived from L chondrite material and exhibiting bulk FeNi metal and sulphide depletion with respect to it.

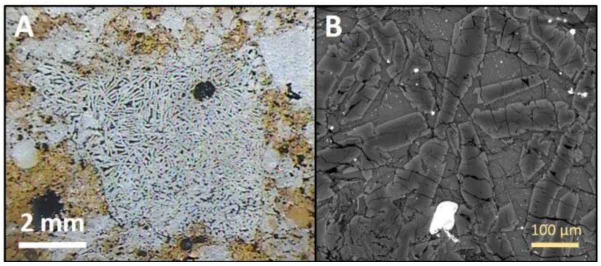

Figure 2: (A) Thin section image of NWA 869 fragment M57460, showing a spinifex-textured impact melt clast; (B) BSE image of zoned olivine in a fine matrix of olivine and feldspar + immiscible sulphide.

Sulphide-rich matrix zones: The clastic matrix for NWA 869 is overall distinctly enriched in disseminated sulphides, but in some cm-scale zones this enrichment is pronounced, to produce net-textured sulphide that encompasses matrix constituents. In hand sample and in thin section, these sulphide-rich zones superficially look like clasts but have transitional contact with the host matrix and are themselves matrix. They can be distinguished in hand sample by their black appearance and markedly increased dark Fe-oxidation staining.

Ferromagnesian silicates in a sulphide-rich zone in M57461 (Fig. 3) have anomalous compositions, with both olivine ($Fa_{22.61\pm0.25}$; n=10) and Ca-poor pyroxene ($Fs_{19.86\pm0.33}$; n=7) having lower Fe than their NWA 869 matrix and clast counterparts. FeNi metal blebs have a corroded appearance in BSE images, and the abundant troilite shows development of irregular subparallel cracks and local alteration to pentlandite along veinlike zones. Micro-XRD identifies pyrrhotite along with the troilite. Chromite occurs as typically much larger grains than in the NWA 869 matrix, and is intimately associated with magnetite and troilite (Fig 3B).

Discussion:

Variation in matrix sulphide content, systematic depletion of silicate Fe in sulphide-rich zones, and the variety in L chondrite-derivative clasts, including impact melt clasts, suggest that NWA 869 represents a sample from a dynamic, impact-dominated environment at the surface of an L chondrite parent body [2-5]. Beyond mechanical mixing of clasts, comminution and the generation of impact melt, the NWA 869 samples examined in this study are also a witness to the mobility of sulphur in the regolith breccia. Sulphides and sulphur, along with chromite tend to be most easily mobilized during impact events [8]. NWA 869 L-affinity igneous clasts and matrix examined in this work and elsewhere [2,5] show evidence of sulphide depletion relative to L chondrite norms, suggesting that the impact process itself was driving S mobility. The overall matrix of the NWA 869 regolith breccia has a greater, well-distributed sulphide content (representing deposition of S), and in this work is also seen to have local cm-sized zones of marked sulphide and chromite enrichment (Fig. 3). At these zones within NWA 869, it is possible that sulphidation took place, drawing Fe from the matrix ferromagnesian silicates. Sulphur mobility and sulphidation may be a potent nearsurface process in asteroidal regolith.

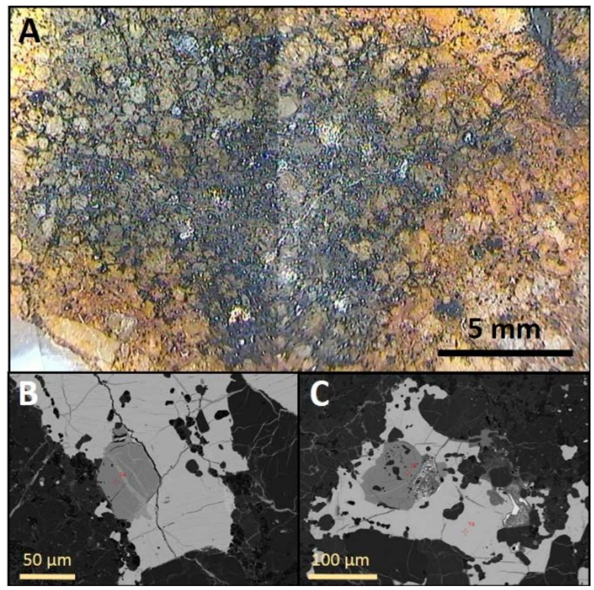

Figure 3: (A) Thin section image of sulphide-rich zone in NWA 869 fragment M57461; (B,C) BSE images of web network sulphides + chromite, magnetite and minor FeNi metal set within clinopyroxene, enstatite, olivine and felspar.

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