REGOLITH PROCESSING ON L CHONDRITES AS WITNESSED BY NWA 869

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1. 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 (Fig. 1), 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 cm² of NWA 869 breccia surface area for examination and subsampling. Here we report on observed matrix and clast textural relationships in four ROM samples M57459 – M57461 from two individuals, following the NWA 869 work of Metzler et al. [2] and Hyde et al. [5] on other individual pieces, and discuss possible constraints on early solar system regolith processing on this L chondrite parent body.

2. Samples & Methods

Following inspection of cut slabs and ends from NWA 869 individuals (Fig. 1), polished thin sections were prepared of regions exhibiting unusual clasts, matrix and notable clast-matrix relationships. Four samples (M57459 to M57461) are examined in detail in this work. Electron probe microanalysis (EPMA) of silicates, sulphides and oxides was conducted with Queen’s University using a JEOL JXA-8200 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, on cut surfaces and polished thin sections.

3. Observations

NWA 869 consists entirely of lithified clastic material, including a highly comminuted crystalline matrix. Most visible clasts at hand sample and thin section scale are of L 5-6 chondrite [1,2] but other, more exotic clasts are present, including idiomorphic grey impact melt rocks [2], rare silica-bearing clasts [2,5] and clasts representing achondritic impact melt inclusions [5].

Matrix and S-rich matrix zones:

Matrix and other matrix constituents (chondrules, single crystals) are typically enshrouded by a fine, dark, 1-3-µm mantle of crystalline debris (Figs. 2,5). Most notably, disseminated sulphide dominates ~2:1 over FeNi metal blebs as the dense, metal rich phase in the matrix, whereas they are subequal in L clast rich breccia. The sulphide tends to lie interstitially between clastic fragments and is in places gangue as ~3 mm blebs. A noted previous [2] clast in the NWA 869 regolith breccia has – in bulk – retained low petrographic type 3 conditions. In some cm-scale zones this enrichment is pronounced, to produce net-textured sulphide that encompasses matrix constituents (Fig. 3). 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.

Ferromagnesian silicates in a sulphide-rich zone in sample M57461 (Fig. 2) have anomalous compositions, with both olivine (Fa22±3, Fa27±3, n=10) and Ca-poor pyroxene (Fs29±2, Fs14±2, 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 (Fig. 3). Micro-XRD identifies pyrrhotite along with the troilite (Fig. 4). Chlorite occurs as typically much larger grains than in the NWA 869 matrix and is intimately associated with magnetite and troilite.

Spinifex-textured melt clasts:

Samples M57460 and M57459, showing a spinifex-textured impact melt clast (yellow box; B), present inclusions of olivine and FeNi metal blebs in a fine matrix of olivine and feldspar + sulphide.

Spinifex-textured melt clasts: Samples M57460 and M57459, showing a spinifex-textured impact melt clast (yellow box; B). BSE image of zoned olivine in a fine matrix of olivine and feldspar + sulphide.

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 mobilised 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 (Figs. 2,3,9). 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.

4. 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 mobilised 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 (Figs. 2,3,9). 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.