

A TEM INVESTIGATION OF THE FINE-GRAINED MATRIX OF THE MARTIAN BASALTIC BRECCIA NWA 7034. N. Muttik¹, L.P. Keller², C.B. Agee¹, F.M. McCubbin¹, A.R. Santos¹, Z. Rahman²,
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Introduction: The martian basaltic breccia NWA 7034 [1] is characterized by fine-grained groundmass containing several different types of mineral grains and lithologic clasts [2, 3]. The matrix composition closely resembles Martian crustal rock and soil composition measured by recent rover and orbiter missions [4].

The groundmass/matrix in NWA 7034 is texturally and mineralogically heterogeneous and has variable textures ranging from domains of μm to sub- μm sized crystals and fragments to regions of plumose quenched melt. There may be matrices contained within matrices (Figure 1). Mineralogically, the fine-grained groundmass of NWA 7034 consists of feldspar, pyroxene, magnetite, maghemite/hematite, Cl-rich apatite, ilmenite, chromite, pyrite, and ferric oxide hydroxide phase identified by electron microprobe analysis, which are the same phases that occur in the coarse grained portion of the rock [1].

The first results of NWA 7034 [1] suggest that the brecciation of this martian meteorite may have formed due to eruptive volcanic processes; however, impact related brecciation processes have been proposed for paired meteorites NWA 7533 and NWA 7475 [5,6]. Due to the very fine grain size of matrix, its textural details are difficult to resolve by optical and microprobe observations. In order to examine the potential nature of brecciation, transmission electron microscopy (TEM) studies combined with focused ion-beam technique (FIB) has been undertaken. Here we present the preliminary observations of fine-grained groundmass of NWA 7034 from different matrix areas by describing its textural and mineralogical variations and microstructural characteristics.

Material and methods: The FIB sections for TEM analysis were produced from different selected regions of martian breccia NWA 7034 matrix (Figure 1) using the FEI Quanta 3D600 FIB at Johnson Space Center. FIB samples were removed from the thin section using in situ lift-out technique. TEM images, diffraction and chemical data were obtained using the JEOL 2500SE 200 keV field-emission scanning-transmission electron microscope (FE-STEM) equipped with a Noran thin window energy-dispersive X-ray (EDX) spectrometer.

Results: The TEM investigation confirms that the matrix of NWA 7034 is mineralogically heterogeneous nano-crystalline assemblage with average grain sizes of 200-300 nm; however, smaller and also larger crystals of all phases are observed (Figure 2). Textures and mineral composition observed in extracted FIB section from the light colored clast (appears light gray in BSE mode) area are identical to those seen in the darker matrix area (Figure 1). The mineralogy of different matrix phases was identified using selected area electron diffraction and elemental analysis. The matrix mainly consists of fine-grained plagioclase and pyroxene. Crystal morphologies are rounded, irregular and occasionally subhedral. Although very fine-grained, many matrix crystals show a granoblastic texture and common triple junctions (Figure 2) that likely formed during a short-term, relatively low temperature, thermal event. A short duration heating event prevented significant grain coarsening. Cl-rich apatite is also a relatively common phase in the matrix with the size ranging from 200 nm to 300 nm. To date, we have not observed olivine in the matrix of NWA 7034.

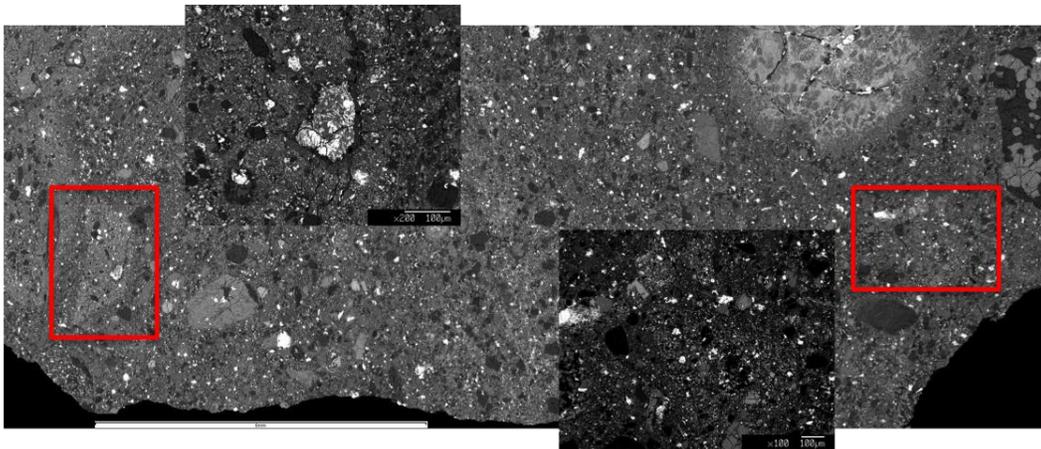


Figure 1. BSE image of NWA 7034 section showing the two different matrix areas analyzed by TEM. Scale bar 6 mm and 100 μm .

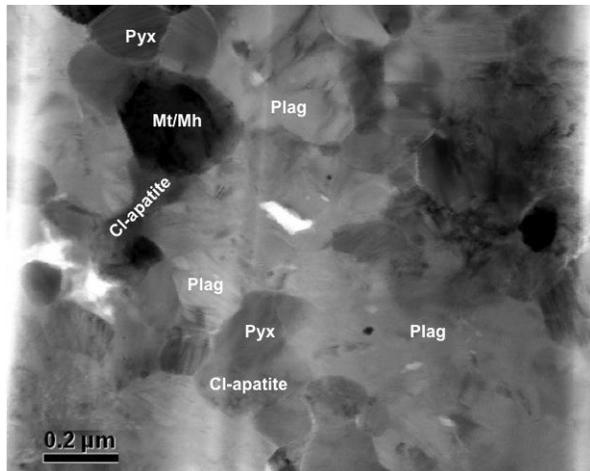


Figure 2. BF STEM image showing fine-crystalline matrix consisting mainly of plagioclase (Plag), pyroxene (Pyx) and in some extent Cl-rich apatite. Main Fe-rich phases are magnetite (Mt) and maghemite (Mh). Note the triple junctions.

Our preliminary TEM observations indicate that magnetite and maghemite are the main Fe-rich phases in the matrix, heterogeneously distributed amongst pyroxene and plagioclase, with their shapes dominantly being rounded and irregular (Figure 3). The occurrence of ~300 nm oxide particles are the most common and were found in both regions, however even larger magnetite particles are present and smaller spheroidal clasts of 10 nm size can be found.

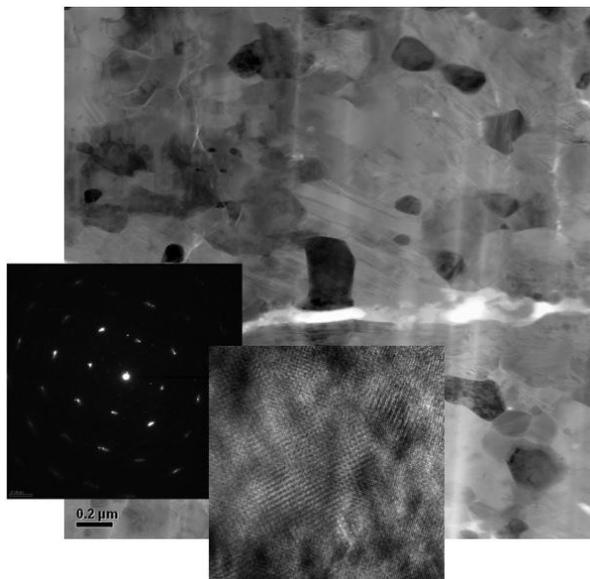


Figure 3. BF STEM image showing the distribution of magnetite and maghemite (top). SAED pattern and HRTEM image of observed maghemite superstructure. Scale bar 2nm (HRTEM).

In addition, we observed regions of fine-grained phyllosilicates along grain boundaries in orthopyroxene (Figure 4). High-resolution TEM images show basal spacings measuring 10-11 Å consistent with smectite-

type clay, probably Fe-rich saponite given their compositions. The occurrence of these secondary phases are an indication of aqueous activity/water-rock interaction; however, it is difficult to distinguish between Martian origin aqueous activity and possible terrestrial alteration. This is the first documented report of phyllosilicate type minerals in NWA 7034.

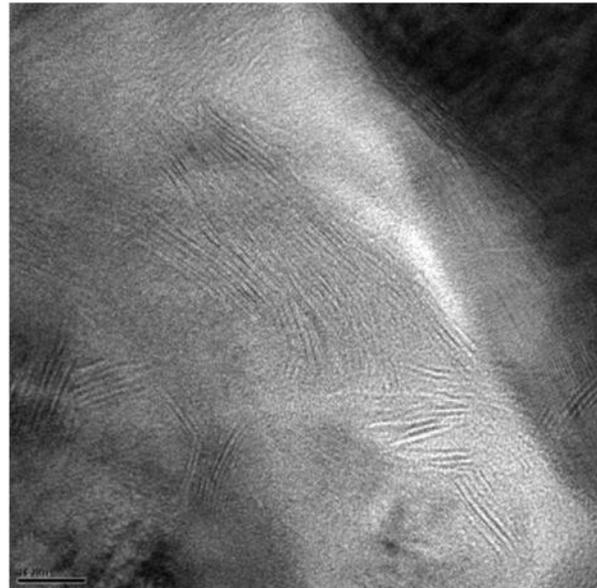


Figure 4. HRTEM image of detected phyllosilicates. Scale bar 10 nm.

Interpretation: Preliminary microtextural investigations of the fine-grained matrix from NWA 7034 show textural evidence of a short term heating event resulting in partially equilibrated textures. It is evident that the entire assemblage has been heated to various extent as the two different matrix assemblages had similar textural features and did not show many textural differences. Humayun et al. [5] have been classifying these different matrices in paired meteorite NWA 7533 as (1) clast laden impact melt rocks (CLIRM) (light gray fine-grained areas in BSE imaging mode) (2) fine-grained interclast crystalline matrix (dark area in BSE imaging mode). According to their investigations, these fine-grained materials contain a substantial windblown dust/martian soil component, however our investigations did not identify any typical cementing agents.

Further studies are needed to address the proposed thermal metamorphism. This thermal event likely occurred after the final assembly of the breccia, which is supported by similar Pb-Pb ages of phosphates in all matrix domains of NWA 7034 [7].

References: [1] Agee, C.B. et al. (2013) *Science* 339, 780-785. [2] Santos, A.R. et al (2013) *44th LPSC*, #2533. [3] Santos, A.R. et al (2013) *44th LPSC*, #5284. [4] McSween, H.Y. et al. (2009) *Science* 324, 736-739. [5] Humayun, M. et al. (2013) *Nature* 503, 513-516. [6] Wittman, A. et al. (2013) *76th MetSoc*, # 5272. [7] Yin, Q-z. et al (2014) *45th LPSC*, This volume.