# Understanding the Early Martian Environment through the Inventory of Breccia Clasts in Northwest Africa

## Conference or Workshop Item

**UNDERSTANDING THE EARLY MARTIAN ENVIRONMENT THROUGH THE INVENTORY OF BRECCIA CLASTS IN NORTHWEST AFRICA 7034.** G. M. Jacobs[1*], F. J. Abernethy[1], M. Anand[1,2], I. A. Franchi[1], and M. M. Grady[1,2], [1]Planetary and Space Sciences, The Open University, Milton Keynes, MK7 6AA, UK, [2]Department of Earth Sciences, Natural History Museum, London, SW7 5BD, UK. * George.jacobs@open.ac.uk.

**Introduction:** Martian meteorite Northwest Africa (NWA) 7034 and its pairs form a unique group of martian breccias [1]. Breccias are rocks that contain angular lithic fragments (clasts) supported by a fine grained matrix; the clasts may come from any type of rock, depending on sources and depositional conditions [2]. In this way, a breccia may be considered as a whole suite of rock samples: NWA 7034 contains clasts of lithologies not seen in other martian meteorites as well as lithologies that are a better match for rover data than igneous martian meteorites [1, 3]. In addition to its wide array of lithologies, NWA 7034 also samples martian geological history spanning a relatively large slice of time: from its formation at ~ 4.4 Ga, to its most recent isotope resetting at ~ 1.3 Ga [1, 3-6]. Both these attributes make NWA 7034 ideal for the study of past enviromental conditions on Mars.

As well as itself being a breccia, NWA 7034 contains clasts of breccia. These are fragments of pre-exisiting breccia(s) occurring within the primary breccia of NWA 7034. There are also areas of matrix within matrix [3, 5]. The formation of breccia clasts and clasts of matrix must predate the assembly of NWA 7034; comparison of these objects with each other, and with the main supporting matrix should reveal the range of sources from which the clasts of NWA 7034 are drawn and the extent to which individual clasts experienced aqueous alteration prior to NWA 7034 formation. These considerations are relevant to the greater questions of NWA 7034 formation. By combining shape analysis of breccia clasts with mineralogical and light element isotope data, we are aiming to determine whether individual components came together early and remained as a breccia in the martian regolith for millions of years, or whether the NWA 7034 breccia formed later from pre-existing ancient materials.

**Samples:** Analysis was undertaken on a 1.2 g slice of NWA 7034, measuring approximately 21 x 12 x 2 mm. The top surface was lightly polished with diamond and aluminium oxide paste. Optical and SEM analysis of the polished surface identified three large (> 2 mm) and several small breccia clasts (< 1 mm) on the basis of textural and elemental differences (Figure 1).

**SEM:** The uncoated slice of NWA 7034 was analyzed under low vacuum using an FEI Quanta 3D dual-beam SEM at the Open University. Maps were recorded in BSE mode and EDS at 20 keV and beam current of 0.6nA.

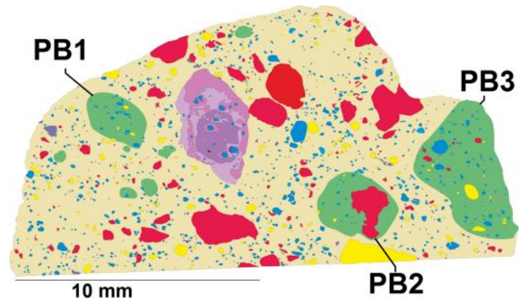


***Figure 1:*** *A false-coloured SEM EDS map of the NWA 7034 slice studied. Breccia clasts are in green.*

**Clast Identification:** A variety of clasts and lithic fragments were found within the slice of NWA 7034. Three of the largest objects were identified as being clasts of breccia; they are labelled PB1, PB2 and PB3 in the figures. Within these clasts were smaller igneous clasts and lithic and single mineral fragments, held within fine-grained matrix; for the purposes of this study, we refer to the clasts within the breccia clasts as sub-clasts. Elemental mapping and point analysis of the clast matrices reveals that the matrix within both PB1 and PB3 is rich in Fe, moderately rich in Ca but depleted in K relative to the primary (i.e., the main supporting) matrix. In contrast, PB2 is very rich in Ca, moderately rich in Na, and poor in Mg and K, relative to the primary matrix. It seems that NWA 7034 contains at least three distinct matrix components. One of the dominant mineralogies of the sub-clasts was pyroxene, with differing chemistries. Pyroxene in sub-clasts from PB1 is low in Ca and Al, those in PB2 are mainly augitic, whilst pyroxene in PB3 has a complete scatter in composition (Figure 2).

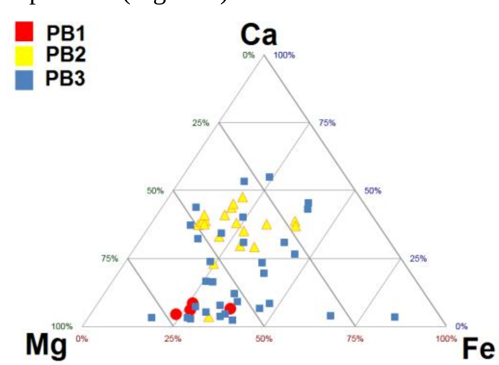


***Figure 2*** *Ca, Fe, and Mg in pyroxenes from sub-clasts within breccia clasts PB1, PB2 and PB3 (SEM).*

**Shape Analysis:** A Computed Tomography (CT) scan of the slice was taken with the Nikon HMXST 225 fitted with Perkin-Elmer detector at the Natural History Museum, London. The CT image confirmed the presence of high density matrices in PB1 and PB3, correlating with their enrichment in Fe (Figure 3). It also showed that PB3 extended through the entire thickness of the sample.

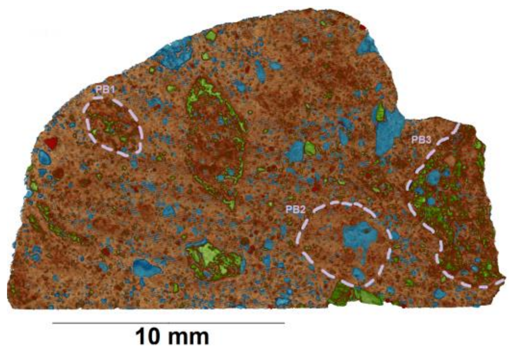


***Figure 3:*** *CT image of NWA 7034 slice, with breccia clasts outlined. Blue: low density (feldspar); brown: medium density (matrix); green: high density (pyroxene and Fe-rich matrix); red: highest density (metal oxides).*

Shape analyses of clasts bounded by primary matrix, and of sub-clasts bounded by matrix within breccia clasts, reveal that each type of matrix bounds clasts of distinct circularity and roundness [7]. However, there is a consistency in clast and sub-clast composition: the most abundant mineral component in the non-breccia clasts are feldspar, followed by pyroxene, and this is the same in the breccia sub-clasts. More detailed processing of the CT data are in progress, to produce a 3D, rather than a 2D, clast shape analyses.

**Isotopic Composition:** The isotopic compositions of the breccia clasts and of primary matrix will be measured in two separate strands: (i) C, N and noble gas abundances and isotopic compositions by gas source mass spectrometry and (ii) U-Pb dating by SIMS. The idea is to clarify whether the breccia clasts sampled lithic populations with different ages and alteration histories, and if they experienced separate resetting events prior to formation of NWA 7034. The light element work is underway, and is being carried out using the Finesse custom-built stepped combustion-mass spectrometry (SC-MS) system at the OU. SIMS work is to be scheduled for later in the year.

Finesse allows simultaneous determination of the abundance and isotopic composition of C, N, Ne and Ar in solid materials. Powdered samples were extracted from targeted areas in the PB breccia clasts using a diamond-tipped burr on a Proxxon micromill MF 70 fitted with microscope eye pieces. The drill system was first tested on baked chips of granitic orthoclase to assess optimal drill-bit size, drilling speed and potential contamination. The first drill site was within PB3, as this proto-breccia extended through the sample, allowing ready extraction of the 5 mg required. The resulting powder was weighed into a platinum envelope for analysis. Once the required samples have been extracted for Finesse analysis, the slice will be repolished to enable SIMS analysis on zircons from the same areas. Subsequently, EPMA of the clasts will be undertaken, to provide more detailed information on the mineral chemistry of the igneous material within the breccias, elucidating the extent to which the breccias had shared histories.

**Discussion:** NWA 7034 contains clasts of breccias with matrices and internal clasts chemically and physically distinct from each other and from the primary matrix and clast types. To account for this, NWA 7034 must sample lithic material from multiple sources (spatially or temporally). The material has interacted with surface fluids and the martian atmosphere to different extents prior to the formation of NWA 7034.

The high Fe content of the matrix in PB1 and PB3 suggests that these breccias are sourced from an Fe-rich rock that was absent from the formation region of PB2 and the primary matrix. Alternatively, PB1 and PB3 experienced interaction with an Fe-rich fluid prior to being aggregated into NWA 7034. A similar argument holds for the enhancement of Ca and depletion of Mg in PB2. The difference in pyroxene composition within each breccia also supports sampling of different sources, possibly different strata within an outcrop, or subsequent alteration of the clasts. The higher circularity of clasts within PB1 and PB3 suggest were sourced from further afield, or otherwise spent longer exposed to weathering action. This may relate to their Fe-rich matrices. Work on the mineralogy and stable and radiogenic isotopic compositions of components present in different clasts, sub-clasts and matrix of NWA 7034, and the chemistry of the igneous clasts within each breccia, should fingerprint the origin and histories of the components of NWA 7034, and allow a better understanding of early Mars.

**References:** [1] Agee C. et al. (2013). *Science 339*, 780-785. [2] Boggs Jr (2001). *Principles of Sedimentology and Stratigraphy* [3] Santos A. et al. (2015). *GCA 157*, 56-85. [4] Yin Q.-Z. et al. (2014) *LPS XLV* #1320. [5] Muttik N. et al. (2014) *LPS XLV*. #2763. [6] McCubbin F. et al. (2016). *JGR Planets 121*, 2120–2149, [7] Jacobs G. et al. (2016). *LPS XLVII*. #2787.

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