EPSC Abstracts
Vol. 12, EPSC2018-1248, 2018
European Planetary Science Congress 2018

Impactor material in new lunar meteorite NWA 10989

Zoe Morland, Katherine Joy
School of Earth and Environmental Sciences, University of Manchester, Williamson Building, Oxford Road, Manchester, M13 9PL, UK. (**zoe.morland@hotmail.co.uk**, Katherine.joy@manchester.ac.uk)

1. Introduction

Lunar meteorites derive from material ejected at escape velocity from impact events on the Moon. The ejected material is subsequently caught by Earth's gravitational field and falls as a meteorite [1].

Analysis of lunar meteorites improves understanding of the whole surface of the Moon, not just areas visited by the Apollo missions [2]. Moreover, they unlock crucial insight into dynamical processes that have affected the inner Solar System [3]. Despite recent investigation, the impact flux and composition of impactor material delivered to the inner Solar System throughout history still remains mysterious [4]. A key time period still yet to be fully understood is the basin forming epoch. Preserved meteoritic material in lunar samples constitute a vital resource to answer these outstanding questions [5]. Here we investigate these records in a newly discovered lunar meteorite.

2. Samples and Methods

North West Africa (NWA) 10989 is a lunar regolith breccia, which means it formed within a few meters of the lunar surface, in a region highly affected by impact reprocessing. It represents the fusion of an ancient regolith soil that was composed of highland and/or mare rocks. The 1 cm sized fragment of NWA 10989 we investigated specifically contains highland granulites, glassy impact melt breccias (GIMBs), clastic impact melt breccias (CIMBs), monomineralic pyroxene and mare basalt within a clastic glassy matrix that includes impact melt spherules and Fe-Ni metal which are indicative regolith components. The Fe-Ni metal is dominantly contained within a single 1.90 × 0.85 mm grain along with several other smaller grains and abundant fine particles in the matrix (Fig. 1a).

At the University of Manchester, the following instruments were used to investigate the sample's mineralogy and chemistry: EDAX environmental scanning electron microscope to obtain close-up back scattered electron (BSE) and whole sample BSE merger images, qualitative compositional energy-dispersive X-ray spectroscopy point spectra and whole sample elemental map; Raman spectrometer to identify cohenite and goethite; and electron probe micro-analyzer to quantitatively measure major element concentrations.

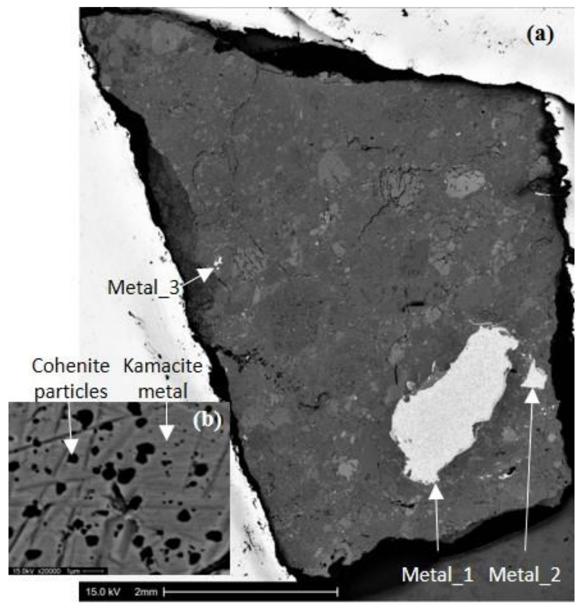

Figure 1: (a) Whole sample BSE image – metallic grains clearly distinguishable as white grains. (b) close-up BSE image of carbon particles found consistently throughout all Fe-Ni metal in the sample.

3. Results and Discussion

Quantitative analysis has confirmed that the metallic grain is composed of predominantly kamacite (low-Ni) with minor amounts of taenitic (high-Ni) material and K-rich schreibersite (Fig. 2a). Comparing the composition of this metal to the meteoritic field (Fig. 2a) suggests that the metal was delivered to the Moon as a meteorite [6]. However, the silicates (olivine, pyroxene and plagioclase) surrounding the metal fragment reflect endogenous lunar compositions (Fig. 2b). The texture and compositional difference between silicates and metal suggest that the meteoritic metal has undergone multiple stages of reprocessing, reheating and recrystallisation since impacting the lunar surface.

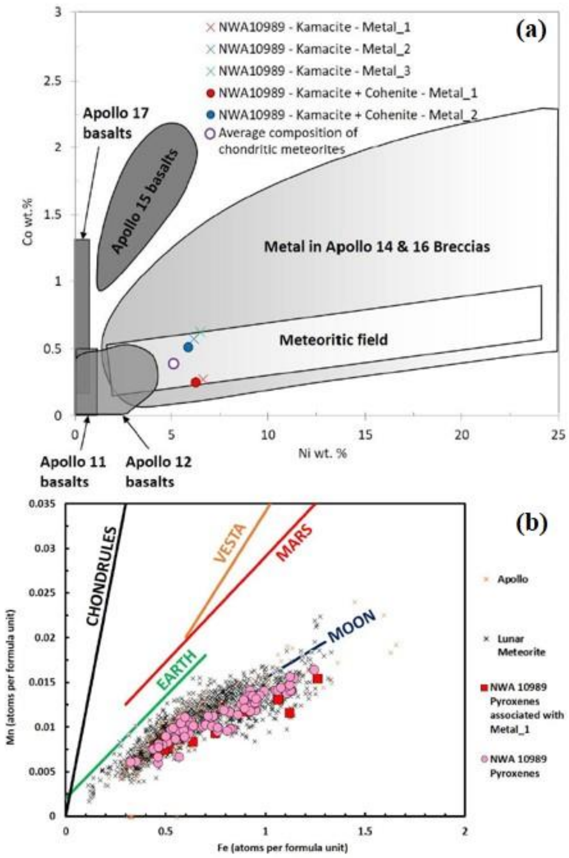

Figure 2: (a) NWA 10989 metallic grain plotting within the meteoritic field, (b) pyroxene grains in contact with the metallic grain showing native lunar composition rather than meteoritic.

Carbon particles were identified across all Fe-Ni metal within this sample (Fig. 1b). Raman analysis lead to identifying them as cohenite. Their presence in the Fe-Ni metal and not softer phases such as troilite, suggest they are not a polishing artefact.

Further 3D analysis of the metal grains is underway to possibly reconstruct the shock, pressure and temperature deformation history of the metal grains. Moreover, it aims to discern whether carbon particles, thought to be cohenite, are intrinsic to the metal. If so, they may provide important information indicative of source material and mechanism and conditions of crystallization. Results from this analysis will enable more accurate and informative inferences to be made about the conditions of formation of this regolith breccia. The source material of the meteoritic metal will be explored in more detail, providing insight into the materials delivered to the Moon at different times in its history [4] and hence the dynamical processes that have affected the inner Solar System [7]. Study of this material will improve our understanding of the nature and budgets of lunar metal in the lunar regolith. This will aid in forthcoming assessments of the Moon's potential as a resource [8], which is important for future lunar exploration plans and *in situ* resource utilization (ISRU) of the lunar surface.

Acknowledgements

Thank you, Martin Goff, for donating the sample.

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