CRYSTALLOGRAPHY OF AN EARLY AMAZONIAN METEORITE: IMPLICATIONS FOR CONDITIONS AT CRYSTALLIZATION

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Introduction: The study of martian meteorites has provided a deeper understanding of volcanism on Mars. Collectively, the small number of samples we have collected and analyzed have begun to answer large-scale questions pertaining to the geological history of the martian surface. Here, we investigate a basaltic shergottite meteorite from the early Amazonian [1] - one of only two currently known martian meteorites that crystallized at this time [1,2]. Shergottites sample a suite of different lithologies, formation ages, ejection ages and volcanic settings [3], therefore careful consideration of each sub-type is critical to building a wider understanding of martian volcanism as a function of both formation age and location.

North-West Africa (NWA) 8159 is the only shergottite classified as an augite basalt [1, 4]. It likely crystallized from an evolved melt at 2.37 ± 0.25 Ga based on Sm-Nd analyses [1], which is much older than the majority of the shergottite group (typically <600 Ma in formation age) [1]. We investigate the crystallization conditions of this early Amazonian rock, and what implications that has for the environment in which it formed.

The aim of this initial crystallographic examination is to qualify and quantify any crystallographic fabrics or alignments present in NWA 8159. Crystallographic textures can be used as an indicator for how the igneous rock was emplaced, for example in a fast-moving flow or in a cumulate setting. This study marks the start of a wider comparative analysis of crystallographic textural variations across the shergottites, with the aim of mapping out any observed disparities within the class.

Methods: Crystallographic information was collected from the surface of an 1-inch round epoxy mount of NWA 8159 (supplied by UNM), prepared at Curtin University. The sample was polished with colloidal silica for 7 hours on a Vibromet polisher to obtain a reflective surface, and then coated with ~5 nm of carbon for conductivity purposes. A backscatter electron (BSE) image was collected at 20 KeV accelerating voltage on the TESCAN TIMA scanning electron microscope (SEM) at the John de Laeter centre (JDLC) at Curtin University. All crystallographic information was then collected using the electron backscatter diffraction technique (EBSD), with a TESCAN MIRA3 SEM and Oxford Instruments Symmetry CMOS detector. Large area maps were created based on crystallographic information obtained at a step size of 1 micrometre.

Phase and orientation information were collected or deduced based on Kikuchi bands recorded by the detector, which were created after interaction with each mineral surface. In this initial study, we focused on the orientation characteristics of the large, poikilitic grains identified as crystalline plagioclase feldspar over a ~3 x 4 mm area. This area alone generated ~15 million data points across all phases.

Analysis and processing of this data was conducted using the Oxford Instruments software package, Channel5. Noise reduction was conducted as per the common protocol [e.g. 5,6], and the larger grains were then added to a subset via grain size thresholding. Grain boundaries were characterized using a 10º misorientation threshold.

Results: Phase analysis of the study area revealed the following mineralogy in the study area away from a large shock vein; clinopyroxene (48%), plagioclase feldspar (36%), magnetite (8%), olivine (3%) and 5% attributed to the Ca-rich minor veins and accessory minerals, such as apatite. This is broadly in agreement with previous mineralogical studies [e.g. 1,4]. Maskelynite was not included here as it is not crystalline and therefore can't be detected via EBSD.

Orientation data is shown in Fig. 1. This is an euler map of the study area displaying the orientation of each grain via color-coding according to the three euler components of the crystallographic orientation. To simplify this map, the same data, with a single representative point for each grain, was then contoured in pole figures and is shown in Fig. 2. This is a lower and upper hemisphere, equal area projection for 3 primary crystallographic axes of plagioclase feldspar (<20-1>, <010> and <001>). Here, we can identify similarities or clusters of the data of specific crystallographic axes via contouring of the point data, indicating the presence or absence of a crystallographic alignment or fabric. A weak clustering of grains is observed in the <010> axis highlighted in red on the contoured plot, which is typically the shortest crystallographic axis in plagioclase. This visualization shows that <010> is commonly parallel to the plane of the sample (i.e. intersects with the edges of the circle), and is oriented along the NE-SW line, with respect to the orientation of the sample (shown by black dotted line in Fig. 2). Notably, there is also a distinct lack of alignment in the other two axes.

Discussion: The presence of an alignment in <010> indicates that a consistent force has been applied to the rock during the final phase of crystallization. There is no apparent alignment in the long crystallographic axis of the plagioclase laths (<001>) indicating the alignment of <010> was not generated by flow, which typically results in a lineation of the longest axis of the grains [e.g. 7].The weak alignment of <010> in the large plagioclase laths is, however, consistent with a compressive or settling texture. <010> is the shortest axis of the plagioclase grains, therefore the grains are stacked perpendicular to the shortest axis, which is likely parallel to the line of the compressive force, for example gravity or impact [e.g. 5]. The low abundance of maskelynite observed within NWA 8159 [1, 4] and size of the aligned laths imply that impact is unlikely to be the driver of this alignment. NWA 8159 remains relatively unshocked compared to other shergottites [1, 4] and impact events rarely align such large grains, particularly in crystalline rocks. We therefore consider this alignment to be the result of gravity-induced settling.

The cumulate texture of the plagioclase phenocrysts 3600is consistent with final crystallization in a shallow or short sill (potentially with interrupted flow to account for the lack of a lineation), or in a shallow lava pool. In both of these proposed scenarios, the finer-grained groundmass would crystallize quickly, but the large phenocrysts- that had likely formed earlier- would be able to settle under gravity. These suggestions are also loosely in agreement with previous studies, where the grain size of the groundmass of NWA 8159 was used to infer a surface lava flow or shallow sill origin [1].

Conclusions and future work: Future work will include analysis targeting the fine-grained groundmass. Although there is a weak alignment, it's possible the large phenocrysts examined here may be too large to be re-oriented by flow. Examination of the finer groundmass will enable a direct comparison with the textures presented here, and an evaluation of any size-dependent alignments. Collectively, this will help us to better understand the final-stage crystallization environment of NWA 8159.

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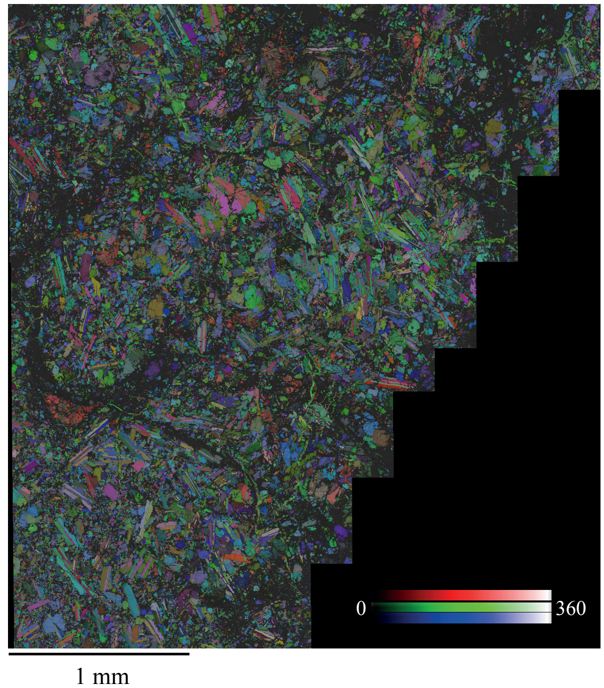

Fig. 1: Euler map of the study region, displaying the orientation of each crystal characterized by the 3 Euler angles in red, green and blue (measured between 0-360 degrees for each angle).

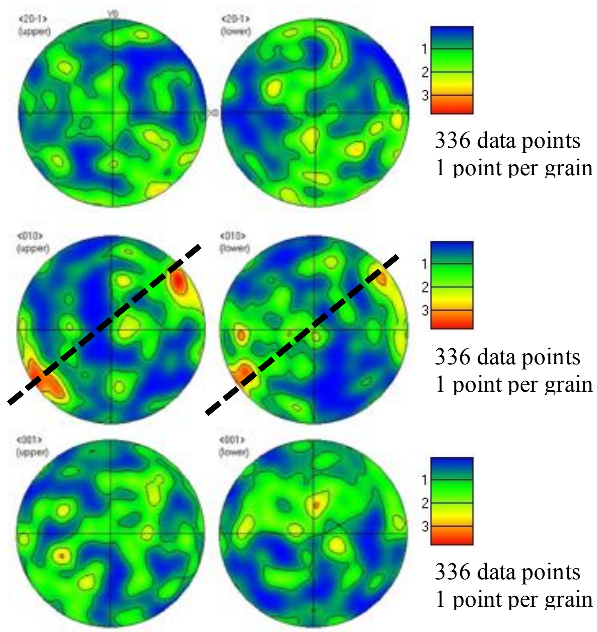

Fig. 2: Lower and upper hemisphere stereographic projections of the contoured orientation data for large plagioclase laths. The legend represents multiples of mean uniform density, or m.u.d., therefore the red colored regions on the plots indicate a higher density of axes which intersect the plot at those orientations. The black dotted line represents the typical <010> axis orientation for the aligned grains.