CRYSTALLIZATION HISTORY OF GABBROIC SHERGOTTITE NWA 6963 AS REVEALED BY PYROXENE ZONING.

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Introduction: NorthWest Africa (NWA) 6963 is an intriguing new coarse grained Martian meteorite that further extends our sample collection both compositionally and texturally [1]. It was originally documented as a basaltic shergottite because the pyroxene compositions [2, 3] and modal abundances are similar to Shergotty. However, recent work reclassified NWA 6963 as an intrusive, gabbroic Martian meteorite because of the large oriented pyroxene crystals [1]. This investigation will focus on NWA 6963 pyroxene zoning profiles and interpreting igneous processes related to its crystallization history.

Compositional zoning of pyroxene crystals in basaltic shergottites have previously been interpreted for petrology [5] and degrees of undercooling [4]. In addition, cooling rates of Martian magmas have been determined experimentally to constrain volcanic processes based on both pyroxene [e.g., 6] and olivine zoning [e.g., 7]. These studies interpret crystallization histories of basaltic shergottites and provide valuble insight of volcanic flows on Mars. However, igneous conditions below the Martian surface can now be constrained with instrusive shergottite NWA 6963. The crystallization history of a gabbroic shergottite is expected to differ from basaltic Martian meteorites due to the nature of instrusive and extrusive igneous conditions. Determining rates of cooling from pyroxene zoning will further constrain the petrogenetic history of NWA 6963. This will provide new information on the nature of instrusive igneous processes within the shallow Martian subsurface.

Sample NWA 6963: NWA 6963 was found in 2011 in Guelmim-Es-Semara, Morocco near the river Oued Touflit [3]. It contains pyroxene and maskelynite grains up to 5 mm in length [1]. NWA 6963 is composed of 65 ± 5 % pyroxene (25 ± 5 % augite and 40 ± 5 % pigeonite), 30 ± 5 % maskelynite, and other minor phases [1]. The two pyroxene phases are in equilibrium with a high crystallization temperature of ~1250 °C and low of ~1000 °C [1]. Therefore, this sample is ideal for investigating pyroxene zoning profiles.

Methods: Major element analyses were done using a Cameca SX 100 electron microprobe at the Open University, UK. Measurement lines were analyzed across twelve pyroxene grains using standard measurement conditions (20 kV, 20 nA; calibration against a standard set of minerals). A 1 μm spot size was used and each measurement was spaced ~5 ± 1 μm apart. Lines were comprised of 40 to 120 measured points depending on grain size. This method produced precise zoing profiles used to interpret NWA 6963 petrogenetic history. Measurements too close to the edge of grains, melt inclusions, sulfides, fractures, or alteration were removed from zoning profiles. Outliers were identified by obvious changes in bulk chemisty, poor oxide weight totals, and visual inspection of back scatter electron (BSE) images. Element maps of three pyroxene grains were produced to better interpret zoning profiles.

Trace elements have recently been analyzed by laser ablation-ICPMS at the Open University, UK. The data is currently being reduced to further interpret pyroxene zoning profiles in NWA 6963.

Pyroxene Geochemistry: Major element data from this study and others show pyroxene chemistry to be augites and pigeonites [2,1]. Pyroxene grains in NWA 6963 have complex zoning profiles with step-function type patterns (Fig. 1). Some grains have sharp steps in composition while others are slightly smoothed out. None of the zoning profiles follow a simple decreasing or parabolic pattern as would be expected from continous *in situ* crystallization [8].

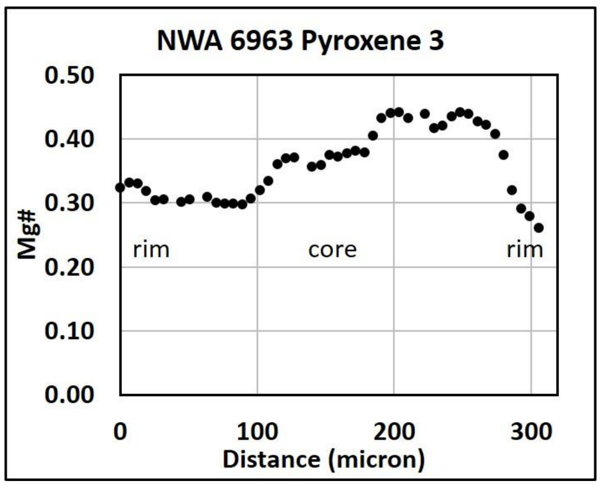

Figure 1: Pyroxene zoning profile in NWA 6963. Measurement line correlates with Fig. 2.

Pyroxene Mg# (MgO wt% / (MgO wt% + FeO wt%) values range from 0.56 to 0.26 with an average of 0.42. Pyroxenes in NWA 6963 have Mg-rich cores and Fe-rich rims similar to basaltic shergottites [5, 9]. SiO_2, TiO_2, and Cr_2O_3 wt% oxides mimick zoning trends of

MgO with concentrations decreasing from core to rim. CaO, Al_2O_3, and MnO wt% oxides are evenly distributed throughout each grain.

Element and BSE maps: Element maps and BSE images were taken of pyroxene grains. Interpreting these maps provides additional insight to major element data lines across pyroxene grains. Examination of BSE images show dark areas across grains which correlate with the highest relative Mg#s.

Pyroxene element maps reveal exosolution lamallae of Ca and Fe in sections of each grain. Lamallae are discontinuous and appear slightly wavy throughout the pyroxene grains. Minor offset in lamellae is likely due to shock [4]. Zoning profile lines were carefully selected to best avoid exsolution lamellae and avoid the influence of secondary shock effects.

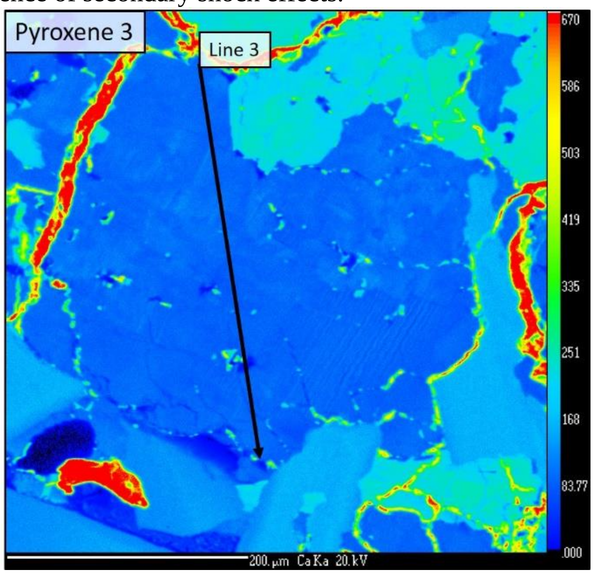

Figure 2: Element map showing Ca composition across a pyroxene grain. Exsolution lamallae can be seen in the lower right side of the grain.

Disscussion: Pyroxene zoning profiles in NWA 6963 have step-function patterns, which suggests multiple phases of cooling recorded in these grains. Unlike volcanic pyroxenes, intrusive minerals are not extruded and do not cool as quickly. Intrusive igneous conditions lead to different grain zoning and crystallization histories. Flat zoning profiles are interpreted to represent a time of very slow cooling and perhaps a long period of equilibrium between the grain and magma. Zoning profile steps or jumps suggest relatively faster cooling rates between slower crystal growth periods. However, some grains have less sharp steps which may be due to diffusion of elements over time [10]. Previous work with numerical modeling of initial step-function zoning has been attributed to changing boundary conditions along a grain, such as magma mixing [10]. However, NWA 6963 represents a partial cumulate rock [1, 11] and the step-pattern, and differences between grains, is presumably related to the accumulation process. Pyroxene zoning profiles in NWA 6963 provide new information on magmatic conditions below the Martian surface at the time of NWA 6963 formation and the cumulate process. The addition of trace element analyses may further constrain unknowns from this study.

References:

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