RAMAN AND INFRARED SPECTROSCOPY OF MARTIAN METEORITE NORTHWEST AFRICA 2737.

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Introduction: Meteorite Northwest Africa 2737 (NWA 2737), the second discovered chassignite, is a dunite derived from the Martian interior [1]. Based on its olivine cumulate nature and high olivine Mg content, NWA 2737 is consistent with crystal accumulation due to fractional crystallization of a primitive basaltic magma [1-3]. Inclusions trapped within the meteorite's primary minerals can preserve valuable information about the magma from which NWA 2737 crystallized [4]. Therefore, melt and fluid inclusions hosted in olivine can elucidate the chemistry of the parental magma body and, consequently, help to constrain Mars' mantle sources and volatile budgets. Here, Raman spectroscopy was utilized to probe mineral phases within inclusions in a thick section sample of NWA 2737. Additionally, a combination of Fourier-Transform Infrared Spectroscopy (FTIR) and Raman spectroscopy was employed to evaluate the modal mineralogy of NWA 2737 as a rapid technique for modal quantification compared with other methods.

Materials and Methods: A fragment of NWA 2737 examined in this study (NWA 2737 470) was prepared for inclusion analysis as a doubly-polished thick section mounted with Krazy Glue on standard petrographic glass, embedded with EPO-TEK 301 epoxy resin, and finished to a thickness of 150 µm. The meteorite fragment is roughly 1 cm^2 in area.

Inclusions within NWA 2737 470 were initially identified using a Leica Microsystems DM 2700 polarization microscope. Olivine grains comprised the majority of the thick section and appeared opaque in most areas. Some olivine grains, however, displayed semitransparent orange-brown patches in transmitted light, which permitted the identification of inclusions. Raman spectra of inclusions were collected using a WITec alpha300 R Raman Imaging Microscope with a 100X ZEISS LD EC Epiplan-NEOFLUAR (NA = 0.75) objective. A 532 nm frequency-doubled Nd:YAG laser with a spot size of about 2 µm was used as the excitation source. Five accumulations, each with an integration time of 45 seconds, were averaged to produce spectra. The laser power at the sample was limited to 1 mW to avoid damaging any volatile compounds in the inclusions.

The modal composition of NWA 2737 470 was evaluated through a combination of FTIR and Raman spectroscopy. First, an infrared reflectance map (Fig. 1) of the meteorite thick section consisting of 347,814 point spectra was acquired using a Thermo Scientific

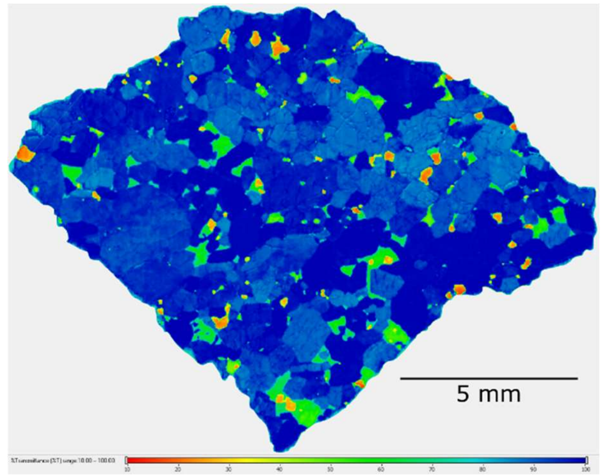

Fig. 1. FTIR reflectance map of NWA 2737 470 illustrating absorption intensity at 911 cm^{-1}. Olivine corresponds to blue regions, pyroxenes and feldspathic glass to green regions, and chromite to orange regions. Different shades of blue reflect different olivine crystallographic orientations.

Nicolet iN10 MX FTIR Imaging Microscope, yielding a two-dimensional spectral profile of the sample in under an hour. Compositional phases were identified utilizing the OMNIC Picta image analysis software, and the associated spectra were split from the IR map as representative end-members. Multiple end-members of the same phase were acquired since various crystallographic orientations of a phase (e.g. olivine) can produce slightly different IR spectra. Phase identities were confirmed by matching their Raman spectra with known spectra in the RRUFF Project database [5] utilizing the WITec TrueMatch software. Next, end-member spectra were incorporated into a deconvolution algorithm that utilized the method of non-negative least squares to model each raw spectrum in the IR map with a weighted linear combination of the end-member spectra. Finally, end-members representative of the thick section backing material were discarded, and modal percentages corresponding to different orientations of the same phase were combined to produce the overall mineral mode.

Modal Composition: NWA 2737 470's modal composition consists of 85.3% olivine, 5.3% orthopyroxene, 3.7% clinopyroxene, 3.6% chromite, and 2.0% feldspathic glass. These results reaffirm the olivine cumulatic nature of NWA 2737 and agree well with those determined in prior studies although the proportion of orthopyroxene is higher than previously

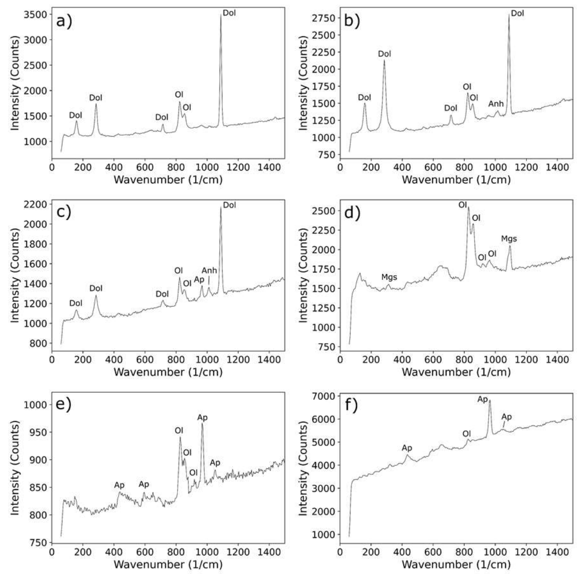

Fig. 2. Selected Raman spectra of inclusions containing daughter phases with labeled peaks. a) Dolomite (Dol) peaks at 158, 285, 715, and 1088 cm^{-1} with host olivine (Ol) peaks at 823 and 855 cm^{-1}. b) Anhydrite (Anh) peak at 1016 cm^{-1} with dolomite and host olivine. c) Apatite peak at 960 cm^{-1} with anhydrite, dolomite, and host olivine. d) Magnesite (Mgs) peaks at 328 and 1093 cm^{-1} with host olivine. e) Apatite (Ap) peaks at 437, 595, 969, and 1049 cm^{-1} with host olivine. f) Apatite peaks at 434, 964, and 1043 cm^{-1} with host olivine. Peak assignments were interpreted based on spectral information from [7] and RRUFF Project database closest match results. Mineral abbreviations are taken from [8].

reported [1, 2]. The closest matching results of major phase Raman spectra to those in the RRUFF Project database indicate that olivine, orthopyroxene, and chromite are all Mg-rich. The results for clinopyroxene indicate compositions ranging from diopside to augite. Additionally, the dark color of olivine grains results from iron-nickel alloy nanoparticles that formed following a large shock event ~170 Ma on Mars [2, 6].

Inclusion Contents: Raman analysis of inclusions revealed the presence of daughter phases containing C, P, and S, including dolomite, magnesite, apatite, and anhydrite (Fig. 2); these phases were occasionally observed in association with silicate and oxide phases such as olivine, orthopyroxene, clinopyroxene, and chromite. The presence of apatite may indicate saturation of certain volatile elements due to the crystallization of the host mineral (olivine), driving the crystallization of daughter minerals that reflect the chemistry of the evolved melt within the inclusion [4]. Sulfides were identified in previous studies of NWA 2737, both as an interstitial and a melt inclusion phase [1-3]. The oxidation of the parental melt would have eventually induced sulfate saturation, promoting the precipitation of anhydrite identified in melt inclusions [9]. Alternatively, anhydrite could be an alteration phase as found recently on Jezero Crater [10]. Carbonates were likely precipitated as in situ immiscible phases within melt inclusions [4] or by a secondary reaction of the CO_2 fluid phase with the olivine host or high-MgO glass [11]. Regardless, either scenario implies that the entrapped melt was rich in CO_2. Although no CO_2 peaks have yet been observed in Raman spectra of fluid inclusions in the examined thick section, the presence of carbonate daughter phases in melt inclusions testify to significant CO_2 contents in the parental melt.

NWA 2737 Parental Magma Composition: Previous studies of NWA 2737 whole-rock and melt inclusion chemistry have suggested that the meteorite crystallized from a basaltic magma relatively enriched in incompatible elements and containing roughly 0.48–0.67 wt% water [1, 3]. Although no nominally hydrous phases were identified in this study, the existence of carbonates and sulfates in NWA 2737 470 melt inclusions supports the notion that NWA 2737's parental magma contained a significant proportion of volatile elements such as C and S.

Future Direction: 3D Raman scans of fluid and melt inclusions in NWA 2737 470 will aid in the identification of daughter phases and enable precise mapping of the spatial distribution of daughter phases within inclusions. This will further elucidate the nature of post-entrapment melt inclusion and daughter phase crystallization in NWA 2737.

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Acknowledgments: This work was supported by the Summer Undergraduate Program for Planetary Research (SUPPR) and the LPI Cooperative Agreement. Additional project funding from NASA award No. 20-SSW20-0066 "Reconstructing the melt composition and volatile record of Chassignite NWA 2737."