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The ungrouped achondrite Northwest Africa (NWA) 7325: Spectral reflectance properties and implications for parent body identification

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ABSTRACT

We have measured reflectance spectra (0.35–25.0 µm) of different size powders of the ungrouped achondrite NWA 7325 in order to facilitate spectroscopic identification of its parent body. Previous work has suggested that the meteorite may have come from the planet Mercury based on its oxidation state. The 0.35–2.5 µm reflectance spectra of NWA 7325 exhibit absorption bands that can be attributed to the presence of chromium-bearing diopside and possibly to Ca-rich plagioclase. Spectral evidence for olivine is generally lacking, likely due to interference from stronger diopside absorption bands. With increasing grain size, albedo decreases while absorption band depths increase. The absorption bands are unique in the sense that they allow for the identification of the Cr-rich diopside in NWA 7325. The mid-infrared spectra are similar to those measured by previous investigators, and enable detection of the major silicates in NWA 7325, including more robust identification of olivine and plagioclase feldspar. We find no spectroscopic or compositional evidence supporting a link to Mercury as a possible parent body, even accounting for plausible spectrum-altering processes. In terms of a link to an asteroidal parent body, the most confident link would be made based on the unique Cr-diopside-related absorption bands in the 0.65, 1.05, and 2.3 µm regions. At present, the closest spectral match we have found is with asteroid 10,537 (1991 RY16).

1. Introduction

The origin and early history of the solar system are still not completely understood. Many meteorites represent remnants of their parent bodies that record the conditions prevalent in the solar system at the time of their formation. Achondrites are of particular interest because they represent samples of bodies that underwent differentiation, thereby providing a record of heating conditions and possible mechanisms that operated in the early solar system. Within the achondrites, those that are spectroscopically unique are of particular value because they have a better chance of being able to be linked to a specific parent body. As part of a larger study of mineralogically and spectroscopically unique achondrites, we report here the results of a spectroscopic study of the unique achondrite Northwest Africa (NWA) 7325.

NWA 7325 likely represents a sample of an ancient differentiated crust, of cumulate rather than residue origin (Barrat et al., 2015). Some investigators have suggested that it may represent a sample of the planet Mercury, based on tenuous evidence that is discussed below. NWA 7325 has an ancient crystallization age (~4563.4–4563.10 Ma; Koefoed et al., 2016), indicating that it crystallized almost contemporaneously with the oldest chondrites, such as the angrites. Recently, Boyle et al. (2017) and Goodrich et al. (2017) found compositional similarities between NWA 7325 and rare xenolithic clasts present in some polymict ureilites (Ikeda et al., 2000; Kita et al., 2004; Goodrich et al., 2017). Identifying a parent body for this meteorite would provide important constraints into the early thermal evolution of the solar system.

NWA 7325 was found in Morocco in 2012, and consists of 35 dark green, fresh-looking stones with a total mass of 345 g; additional finds have brought the total mass to >1 kg (Ruzicka et al., 2015). It has been classified as an ungrouped achondrite. It has a medium-grained plutonic igneous texture, with possible partially resorbed olivine grains (Irving et al., 2013). Oxygen isotope data for NWA 7325 plot on the CCAM line, and within the range for ureilites and extension of trends of winonaites and acapulcoites/lodranites (Irving et al., 2013; Jabeen et al., 2014; Barrat et al., 2015; Weber et al., 2016; Goodrich et al., 2017).

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NWA 7325 has been studied quite extensively by petrography, mineralogy, and characterized compositionally, isotopically, and by mid-infrared spectroscopy (Irving et al., 2013; Jabeen et al., 2014; Weber et al., 2014; Kita et al., 2014; Sutton et al., 2014, 2017). Modal mineral abundances as determined by different investigators vary somewhat, but this meteorite is composed predominantly of low-Fe mafic silicates and plagioclase feldspar. The low-Fe mafic silicates include olivine (~10–16 areal or vol.%; $Fa_{\sim 2.5}$), 25–30 areal or vol. % pyroxene; $Fs_{\sim 0.9}Wo_{\sim 45.3}$), plagioclase feldspar (55–60 areal or vol.%; $An_{\sim 90}$), and trace amounts of sulfides and metal (Irving et al., 2013; Barrat et al., 2015; Weber et al., 2016; Goodrich et al., 2017). Similar modal mineral abundances were found by Goodrich et al. (2017), Irving et al. (2013), and Barrat et al. (2015), but these differ from the results of Weber et al. (2016), who reported 2% olivine, 44% pyroxene, and 54% plagioclase.

The mafic silicates share some broad similarities with other primitive achondrites, such as winonaites, acapulcoites, and lodranites, which include low-Fe content olivine and pyroxene, but differ in many other respects (Goodrich et al., 2017). For instance, the combination of high An plagioclase feldspar and very magnesian mafic silicates appears to be unique among achondrites (Goodrich et al., 2017). However, one notable aspect of the pyroxene is that it contains appreciable chromium (0.92 wt% Cr_2O_3) (Goodrich et al., 2017).

The mid-infrared spectroscopic properties of NWA 7235 have been measured by Weber et al. (2016) and Goodrich et al. (2017) on a polished thin section in reflectance and a polished thick section in emissivity, respectively. They found that these mid-IR spectra matched the independently determined modal mineralogy of their samples quite well using linear unmixing with spectral libraries. They also concluded that the meteorite's mid-IR spectral properties are unique, consistent with its unique mineralogy.

We have studied the spectral reflectance properties of multiple size powders of NWA 7325 from the visible region (0.35 µm) to the mid-infrared (25 µm). The intent of the mid-IR measurements was to acquire additional spectroscopic data for this meteorite as it appears to be petrologically heterogeneous, and also because previous spectroscopic measurements were conducted on polished sections, not powders. The <2.5 µm measurements were conducted because this meteorite has not been previously characterized in this wavelength region, and because such data could be used for comparison with reflectance spectra of possible parent bodies (which are much more extensive than mid-IR observational spectra).

2. Methodology

2.1. Sample description

A 1.58 g sample of NWA 7325 that consisted of a friable main mass and some disaggregrated, mostly coarse grains, was obtained from a commercial dealer. The sample consisted largely of unweathered (rust-free) regions plus ~30% rusty looking areas on the main mass and some of the grains. The sample was gently disaggregated and the fragments were separated into two groups: with and without visible rust by optical microscopy. The two separates were then spectrally characterized; they were subsequently ground to <150 µm grain size using an alumina mortar and pestle and dry sieved, and spectrally characterized again. After these measurements, both separates were further ground and dry sieved to <45 µm, and spectrally characterized a final time. Sample powders were poured into aluminum sample holders and the edge of a glass slide was drawn across the sample to provide a flat matte surface for the spectral measurements.

2.2. Spectral measurements

Reflectance spectra were acquired with an ASD Field Spec Pro HR spectrometer (0.35–2.5 µm) and sample illumination was provided by a collimated 50-watt quartz-tungsten-halogen light source with a viewing geometry of incidence angle $i = 30°$ and emergence angle $e = 0°$. Spectra were measured relative to a calibrated Spectralon® standard and corrected for occasional minor offsets at 1.00 and 1.83 µm, where detector changeovers occur. Spectral resolution varies between ~2 and 7 nm, and data are acquired at 1.4 nm intervals, which are then internally resampled by the spectrometer to provide output data at 1 nm intervals. A total of 500 spectra of the standard, dark current, and sample were acquired to improve the signal-to-noise ratio of the measurements.

We applied continuum removal to our spectra to determine the depths, center positions, and areas of absorption features of interest. We divided each spectrum by straight line continua tangent to either side of an absorption feature of interest. The continuum slopes were then removed to correct the band minimum to that of the true band centers (Clark and Roush, 1984).

Reflectance spectra of the powders were also measured over the 1.4–25 µm (7000–400 cm^{-1}) range at 2 cm^{-1} spectral resolution using the University of Winnipeg's Planetary Spectrophotometer Facility's Bruker Vertex 70 FTIR spectrometer. Spectra were measured relative to a calibrated diffuse Infragold® standard at $i = 30°$ and $e = 0°$ using a Specac bidirectional reflectance accessory. A total of 1500 spectra were acquired and averaged to improve the signal-to-noise ratio. The samples were placed in a sealed sample compartment which was purged with dry nitrogen cycled through Drierite® to remove atmospheric water, and were kept in the chamber for a minimum of 6 h prior to the spectral measurements.

2.3. X-ray diffractometry

Powder X-ray diffractometry (XRD) was applied to the <45 µm sieve separates. X-ray diffractograms were acquired as continuous-scan data from 5° to 80° 2θ on a Bruker D8 Advance with a DaVinci automated powder diffractometer. A Bragg-Brentano goniometer with a theta-theta setup was equipped with a 2.5° incident Soller slit, 1.0 mm divergence slit, a 2.0 mm scatter slit, a 0.2 mm receiving slit, a curved secondary graphite monochromator, and a scintillation counter collecting at an increment of 0.02° and integration time of 0.7 s per step. The line focus Co X-ray tube was operated at 40 kV and 40 mA, using a take-off angle of 6°. X-ray diffractograms were analyzed using the BrukerAXS EVA software package and the International Center for Diffraction Data Powder Diffraction File version 2 (ICDD-PDF2). The phases identified by XRD were diopside, anorthite, and forsterite. The rare metal and sulfides that have been found in NWA 7325 by previous investigators were not detected in our X-ray diffractograms. We also tentatively identified lizardite in the rusty fraction, although the diffraction peaks associated with this phase were at the limits of detectability. Other than this phase, the two diffractograms were nearly identical in terms of relative peak heights and positions for the silicates.

3. Results

Below we present and discuss the reflectance spectra of the three size fractions of the two (rusty and clean) separates.

3.1. 2.5–25 µm region

This study complements mid-IR spectroscopic studies of NWA 7325 conducted by Weber et al. (2016) and Goodrich et al. (2017).