UNDERSTANDING COMPOSITIONS OF PLANETARY BODIES THROUGH COMBINED PETROGRAPHY AND NON-DESTRUCTIVE RAMAN STUDIES OF METEORITES.

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Introduction: Asteroids contain valuable information about the formation of our Solar System that can be determined from geochemical and petrological studies of meteorites to reveal information about composition, shock level and textures. Achondrite meteorites are derived from bodies that have undergone high-temperature, high-pressure planetary processes similar to the processes that formed the layers in the Earth (i.e. differentiation). The most abundant of the achondrite group are howardite-eucrite-diogenite (HED) meteorites, which are three different groups thought to originate from the asteroid (4)Vesta [1] from different depths: howardites formed at the upper surface; eucrites in the upper crust; and diogenites in the lower crust/upper mantle [2].

Meteorites are precious samples that exhibit compositions and textures not found in terrestrial samples. Because of this, it is vital that our methods are non-destructive in order to preserve the information available in each sample. This has been a strong basis for our research on materials: developing methods to determine compositional data from samples without causing significant damage. By studying the composition of HED meteorites using non-destructive techniques, we are working to develop a trustworthy method for identifying minerals on asteroid surfaces gathered through data from telescopes and spacecraft. The HED meteorites are suitable samples for understanding the processes in the asteroid belt because their parent body, (4)Vesta, is the second largest asteroid in the belt (i.e. there is a lot of material to study). In addition, Vesta was a target of the NASA DAWN mission and has been studied through observational analysis [3-4]. This data-set may be useful, by allowing us a comparison with which to cross-reference our data, to help establish a reliable identification method. Additionally, knowing the composition of Vesta will provide useful comparisons to a large number of planetary bodies and provide new insight into their formation

Here, we describe the methods that we have developed to analyze terrestrial analogues and meteorites using petrography and Raman analysis. The samples we have used for this study include the terrestrial analogues Theo's Flow (analogue for nakhlite meteorites) and Lathrop Wells (basaltic lava from Nevada, USA). The meteorite samples are the howardites Northwest Africa (NWA) 1929 and Dhofar (Dho) 485. NWA 1929 has eucritic and diogenitic clasts in a fine-grained matrix. Dho 485 also has eucritic and diogenitic clasts set in a well-consolidated matrix. They are both abundant in plagioclase and pyroxene with melt clasts, and have been previously studied for chronometry [5].

Methodology: We began parallel microscopy analysis of terrestrial and meteorite samples to identify the minerals and textures present in our samples. Following this, we utilized micro-Raman spectroscopy because of its ability to target specific locations within 1-5μm radius on the sample and deliver spectral data that can be compared with a wealth of well-documented reference data for many minerals. Raman spectroscopy uses a laser source to excite crystal lattice vibrations, where an area is targeted, a laser is fired and light is re-emitted with a small frequency shift from the original laser frequency. The spectrum of re-emitted light ("the Raman spectrum") is unique to the lattice structure of the mineral. Any laser damage potential was diminished by using a 500 mW 532nm laser with a 10% optical filter to ensure that the measuring process is non-destructive. The first samples analyzed with Raman spectroscopy were Theo's Flow (TSC3.16, depth: 55-60m) [6]. Once we were satisfied with the feasibility of Raman to identify unknown minerals, we moved on to analyze NWA 1929. We have processed and interpreted spectra for the NWA 1929 meteorite sample and will begin with the Dho 485 soon.

Results: The Raman spectra feature many distinct modes with low noise levels. Our Theo's flow samples consist of crystals 200-400μm in diameter, in a fine grain matrix. Raman spectra on the crystals feature sharp modes at 668 and 1014 cm^{-1}, while the matrix features sharp modes at 480 and 508 cm^{-1} (Fig. 2) Other, weaker modes are present, notably at 300-400cm^{-1} on the crystals, and at 150-250cm^{-1} on the matrix. The Raman spectra within a melt clast (Fig. 1) in the NWA 1929 sample suggest that two main minerals are present. One mineral has three sharp modes at 300-400cm^{-1}, two sharp modes at 657 and 670 cm^{-1}, and two sharp modes at 996 and 1005 cm^{-1}. The other mineral closely spectrally resembles the matrix from our Theo's flow sample, with minor differences in peak positions. We suggest that this mineral is a plagioclase.

In addition, we identified enstatite and anorthite within a melt clast in our NWA1929 sample. En_{50-60} is suggested by the positions of the doublet Si-O-Si bending modes [7]; while, the positions of characteristic

Ca-Na plagioclase modes at 487 and 505 cm^{-1}, as well as a 560 cm^{-1} mode indicate that the anorthite composition is close to An$_{75-85}$ [8].

We were able to identify the large crystals in our Theo's flow sample as clinopyroxene from the single Si-O-Si bending mode at 668 cm^{-1}, while the M-O stretching modes at 320, 352, 385 cm^{-1} suggests that the mineral is diopside with Mg over 50 mol% [7]. We determined that the matrix is made of a fine grain albite (Ab$_{80-100}$), based on the similarity between its Raman spectra and that of albite (Ab$_{99}$ R040068) from the RRUFF Project database [9] at 100-600 cm^{-1}, and the positions of characteristic Ca-Na plagioclase modes at 480 and 508 cm^{-1} [8].

Discussion: The data we have gathered to this point illustrates that we are successfully on the way to a diagnostic method of identifying mineral compositions using non-destructive techniques, with a particular focus on combined techniques. Previous work using Raman spectroscopy revealed peak intensity reduction and broadening with increasing shock, as shown through experimentally shocked plagioclases [10]. As we continue to use these techniques to assess HED materials, such broadening may be observed in samples that show significant shock and a broad range of ages [5,10]. This could help us identify different regolith histories of materials. Additionally, tissintite (a high-pressure polymorph of plagioclase) has been previously observed within the shock-melt veins of eucrite NWA8003 [11]. Should we identify similar mineral assemblages, this may help us better understand the shock history of the samples. Overall, the data that we collect can be compared to data from other non-destructive techniques (e.g. [12]), as well as missions that use spectroscopy instruments to allow a deeper understanding of our Solar System.

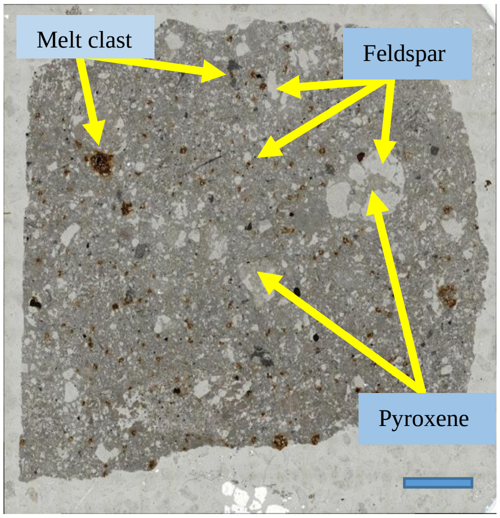

Fig. 1. Plane polarized light image of NWA 1929. Blue bar is 2.5 mm scale.

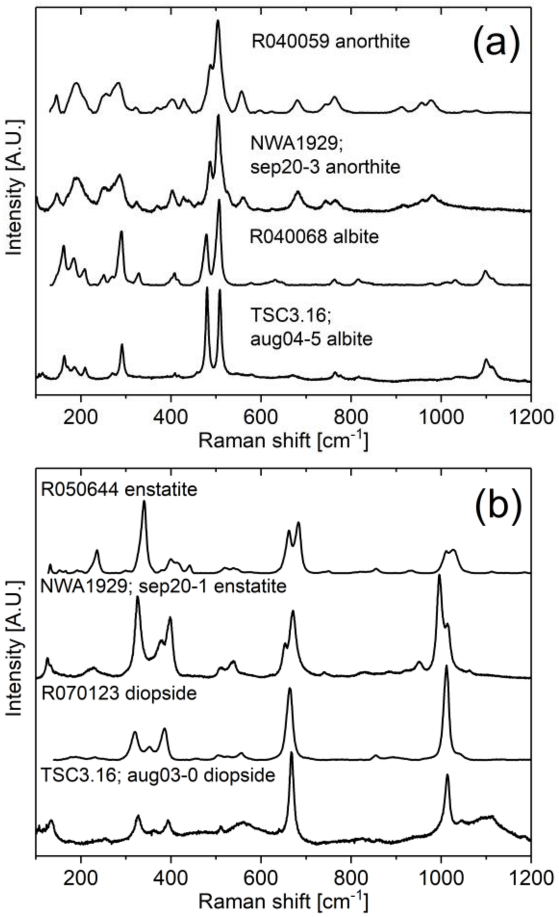

Fig. 2. Representative Raman spectra for a) plagioclases and b) pyroxenes from Theo's flow and NWA 1929, plotted alongside reference spectra of respective mineral species from RRUFF Project database [9].

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