SEEING PAST ALTERATION: REVEALING THE SPECTRAL SIGNATURE OF THE PRIMARY MINERALOGY OF GRA 06128/9.
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Introduction: The meteorite pair Graves Nunataks (GRA) 06128 and 06129 are unique ungrouped achondrite meteorites. They are oxidized, highly albitic (>75% Ab_{84}) pieces of a differentiated asteroid [1]. These meteorites are consistent with the early melting of a volatile rich parent body [1, 2, 3]. It has been suggested that the oxidized olivine-rich brachinite meteorites could be the residual complement of GRA 06128/9 [2, 3]. Unfortunately, the GRA 06128/9 meteorites have experienced significant terrestrial alteration. Previous near-infrared (NIR) spectral studies found that alteration phases dominate, obscuring the spectral characteristics of the primary mineralogy [4]. Here we explore several physical and spectral methods to reduce the effects of terrestrial alteration and determine the spectral signature that characterizes the GRA 06128/9 meteorites to enable us to identify asteroids with compositional affinities to these unique achondrites.

Mechanical Separation: Initial efforts have focused on the mechanical separation of weathered materials from the meteorite samples. As our sample of GRA 06129 appeared to be less altered than the GRA 06128 sample, it was coarsely crushed and separated into three categories based on visual inspection of the grains: lighter material, dark material and weathered/reddened material. These samples were then hand ground and spectrally characterized at the NASA Keck Reflectance Laboratory (RELAB) at Brown University using the bi-directional spectrometer (i=30°, e=0°, resolution of 5 nm) for NIR wavelengths (0.8-2.6 µm) and FTIR bi-conical spectrometer (resolution of 10 cm^{-1}) for mid-infrared (MIR) wavelengths (1-25 µm). The spectra of the three groups of GRA 06129 material and a bulk sample of GRA 06129 [4] are presented in **Fig. 1**.

Spectral Components: Both the NIR and the MIR data suggest that plagioclase and at least one (probably multiple) alteration phases are important spectral components. In the MIR, the Christensen feature at ~7.8 µm indicates the presence of highly albitic plagioclase [5]. The first peak on the Restrahlen plateau is also consistent with plagioclase including the minimum at 9.2 µm [5]. In the bulk and weathered samples, the plagioclase peak at ~9.8 µm is likely convolved with common alteration products such as muscovite and/or nontronite which have OH-stretching vibrations in the 9-10 µm region and bending vibrations in near 12 µm [6, and refs. therein] (**Fig. 2**). Spectral mixing in this wavelength region is linear, so the relatively minor olivine and pyroxene (~10% each, [1]) are not expected to produce strong features.

Spectral mixing in the NIR, however, is highly non-linear. Strongly absorbing mafic minerals and alteration phases are expected to disproportionally affect the spectral signatures despite the high abundance of plagioclase in the meteorite samples. The NIR spectra are consistent with plagioclase, which has a broad absorption feature near 1.25 µm, an alteration phase with a 0.8 µm feature (*e.g.*, nontronite), and another phase with a 1 µm feature (likely olivine, [7]) (**Fig. 3**).

Despite the imperfect manual removal of the terrestrial alteration, the separates reflect the primary mineralogy of GRA 06128/9. The dark material is likely a mixture of plagioclase and mafic minerals, iron rich olivine (~Fo_{40}, [1]) and possibly pyroxene. Although pyroxene is not obviously present in either the bulk meteorite spectrum or the separates in either wavelength region (*e.g.*, lack of 2 µm band in NIR), it is possible that pyroxene at the 5% level could affect the NIR but not the MIR. In the MIR, the dark material seems to have an enhancement on the long wavelength shoulder of the Restrahlen plateau, absent in the light material, which is consistent with the spectral features of olivine. More detailed spectral mixing is being explored.

Additional Approaches to Removing Alteration: The initial attempts at mechanical separation were insufficient; each sub-sample shows evidence for weathering (*e.g.* the 1.4 µm feature, **Fig. 1**). Indeed, because the delineation between grains was made visually, the light material could be a combination of unaltered plagioclase and an alteration product of the same color (*e.g.*, gypsum). Additional methods of reducing terrestrial alteration must be undertaken. These include gentle leaching of the meteorites with weak acid to decompose the more friable alteration products and obtaining spectra of more heavily altered samples to remove the alteration spectrally.

Applications to Asteroids: Identifying the asteroids with compositional affinities to the GRA 06128/9 meteorites is the overall goal of these studies. Reduction of the terrestrial alteration reveals a spectral signature consistent with the known bulk mineralogy. Plagioclase and likely olivine have been identified in the meteorite spectra at both NIR and MIR wavelengths. Thus, a complex 1-1.5 µm feature may be characteristic of the GRA 06128/9 meteorites in the NIR. Both the brachinites and GRA 06128/9 are thought to be the products of partial melting of R-chondrites [2, 3, 8]. Therefore searching for GRA 06128/9-like parent bodies should begin near the proposed brachinite parent bodies, (289) Nenetta and (246) Asporina [9], and their possible collisional families [4, 9].

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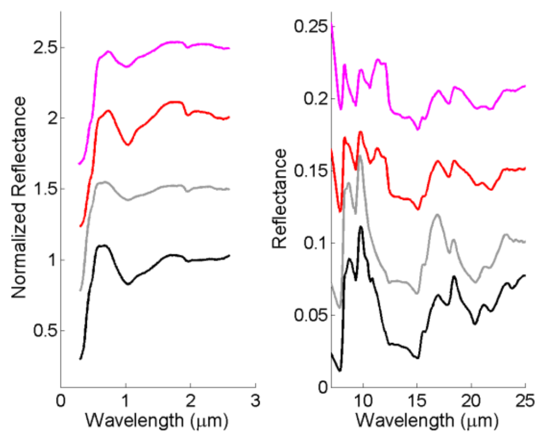
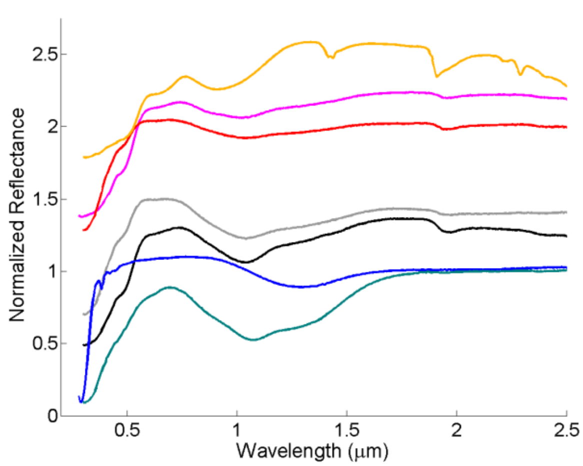


Figure 1: (Left) NIR spectra of (top to bottom): bulk GRA 06129 [6] (pink) and separates: weathered/reddened (red), light (gray), dark (black) material. These spectra are normalized to one at 2.4 µm and offset by 0.5. (Right) MIR reflectance spectra of bulk GRA 06129 and separates, in the same order, offset



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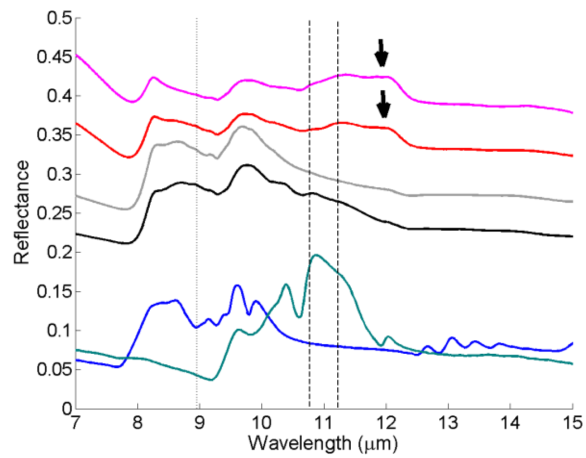

Figure 2: MIR comparison of bulk GRA 06129 (pink, offset 0.35) and separates: weathered (red, offset 0.3), light (gray, offset 0.25.), dark (black, offset 0.2) to possible component minerals: albite [5] (blue, offset 0.05) and Fo_{41} [10] (green). The lines indicate the first plagioclase feature on the Restrahlen plateau (dotted) and olivine features (dashed) which are expressed in the dark material but absent in the light material. Arrows indicate the likely alteration features.

Figure 3: NIR comparison of to possible component minerals. (Top) Bulk GRA 06129 (pink, by offset 1.2) and weathered/reddened (red, offset by 1) are compared to nontronite (yellow, offset 1.6). Light and dark separates seem consistent as the mixture of albite (blue, offset 0.05), and Fo_{41} [10] (green). All spectra are normalized to one at 2.4-µm.