REMOTE SENSING OF LUNAR MINERALOGY: THE GLASS CONUNDRUM, C. M. Pieters[1] and S. Tompkins[2], [1]Department of Geological Sciences, Brown University, Providence RI [Carle_Pieters@brown.edu]; [2]SAIC, Chantilly, VA

The term "lunar glasses" provokes different connotations depending on the context. Common usages include a) pyroclastic deposits consisting of "glass beads" derived from the deep interior, b) melt products created during impact events, and c) the ubiquitous and complex glass-welded weathering products, agglutinates. Each is distinct due to a specific geologic origin and composition, but all contain quench glass in some form. Spectral properties of a wide range of glass-bearing lunar materials is presented elsewhere [1], Discussed here are new spectra for a depth sequence of samples from Apollo 17 core 74002 collected at Shorty Crater. The data provide new insight into why Fe-Ti-rich quench glass is not directly observed remotely. Resolving this mystery allows the extensive glass-rich deposits at Aristarchus to be recognized as low-Ti pyroclastic glass.

An excellent review of the physical properties and geologic settings for pyroclastic deposits can be found in Gaddis et al. [2]. Major pyroclastic deposits are readily identified in remote sensing data [3,4,5]. Nevertheless, the composition of these materials remains poorly characterized due to their unusual/anomalous physical and optical properties. They simply do not fit into multispectral parameter trends used for rocks and soils composed of normal silicates and weathering products, and very little higher spectral resolution data exist.

Pyroclastic glasses and 74002. Shown in Figure 1a are bidirectional laboratory reflectance spectra of three well-known Fe-rich lunar pyroclastic materials. As noted previously [6], the Apollo 15 low-Ti green glass bulk sample (15401) exhibits classic Fe^{2+} quench glass absorption bands near 1.0 and 1.9µm, the crystallized Ti-rich "black beads" from Apollo 17 (74001) exhibit a prominent feature near 0.6 µm attributed to the ultrafine feathering of ilmenite in a silicate matrix, whereas the compositionally equivalent orange glass (74220) exhibits Fe^{2+} bands of quench glass. Although the 1µm glass band of 74220 is distorted, the optical properties of this sample are often used as an endmember for glass studies on the Moon [e.g., 7].

Samples from five levels in the upper drive tube 74002 were selected for analyses: 0.1-0.2; 4-4.5; 7.5-8; 14.5-15; and 23.5-24 cm. Bidirectional spectra for these 5 samples are shown in Fig. 1b. The overall properties of this drive tube were documented both during dissection [8] and with multispectral imaging [9]. Pyroclastic beads make up more than 75% of the drive tube. Orange glass dominates the upper portions, peaking around 8-10 cm, whereas black beads dominate the lower half and all of 74001. Only the upper few cm exhibit any reworking. The spectra of Fig. 1b reflect this mixing of orange and black beads. Our sample from 7.5-8 cm (2217) is dominated by orange glass and, as shown in Fig. 1c, is quite comparable to sample 74220. Similarly, the lowest sample (2219) is almost identical with 74001. The continuum for the uppermost sample is slightly steeper suggesting minor weathering products, perhaps contaminated by local material.

It should be recognized that neither 74220 nor our new 74001.2217 are "pure" orange glass. Both are mixtures and also contain some recrystallized beads. Based on the strength of the glass bands in Fig 1c, however, our 74001.2217 spectrum contains a higher abundance of quench glass. To date, no separate has been made of pure orange glass. Furthermore, the green glass spectrum of Fig 1a is also a mixture of quench glass plus local material. In the 1970's J.B. Adams separated some particularly clean green glass spheres from sample 15401 and these are shown in Fig. 1d.

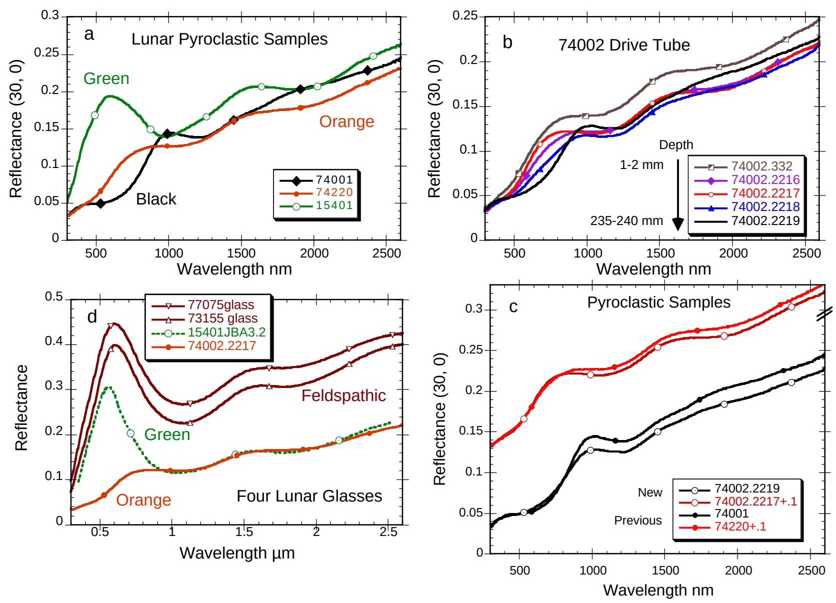


Figure 1. Laboratory spectra of lunar glasses.

Diagnostic glass features. The optical properties of Fe- and Ti-bearing quench glasses under lunar conditions have been thoroughly analyzed [10] using transmission spectra and are illustrated in Figure 1d with both natural glass (15401) and glasses synthesized from Apollo 17 feldspathic melt breccia (77075, 73155) [1]. A broad absorption due to Fe^{2+} in octahedral coordination is seen near 1.0 µm [11]. The strength of this band is directly proportional to the amount of iron in the glass [10]. A weaker band is observed near 1.9 µm due to minor amounts of Fe^{2+} in tetrahedrial coordination [11]. For all compositions, the tetrahedral (1.9µm) band is very weak compared to the octahedral band. As Ti is added, a strong Fe-Ti charge-transfer band creates an absorption edge at short wavelengths, suppressing the visible. Since it is a charge-transfer feature, the strength depends on both the abundance of Fe and of Ti [10].

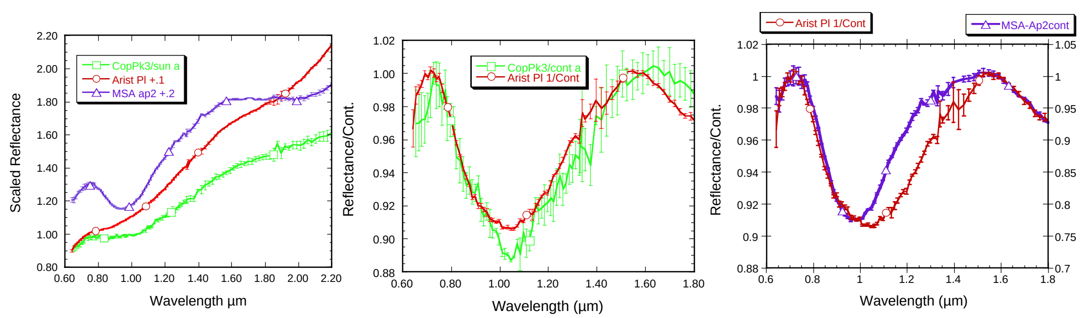
The above discussion is key to why glass features are so rarely observed in spectra of dark mantling deposits. The 1 µm Fe^{2+} octahedral band for orange glass 74220 and our new samples is not only distorted by the prominent Fe-Ti charge transfer absorption in the visible, the actual band strength is not apparent in reflectance data. This is readily seen in Fig. 1d where the two Fe-rich glasses (green and orange) have comparable 1.9 tetrahedral bands, but the apparent strength of the orange glass octahedral 1µm band is radically suppressed by the effects of the charge transfer absorption on the short wavelength edge of the band. [We await a "pure" separate of orange glass to verify.] In reflectance, *only when the sample has relatively little TiO_2 can the 1µm absorption band diagnostic of glass be fully detected.*

Remote observations. Dark mantle deposits at Taurus Littrow and related areas exhibit dark almost featureless spectra and have been interpreted as being dominated by Ti-rich crystallized black beads [3,6,4]. The most prominent pyroclastic deposit that clearly contains glass is the Aristarchus plateau [4,12], although the Ti abundance of the deposit was not determined. NearIR telescopic spectra for mature soil developed on these deposits are shown in Fig. 2. These are compared to diagnostic properties of other materials of interest: olivine in the peaks of Copernicus and typical pyroxene-rich basalt at a mare crater (MSA). Given the conclusions drawn from the 74002 samples, the fact that the strong Aristarchus glass band is not distorted suggests that there is little TiO_2 present. Low-Ti pyroclastic deposits at Aristarchus agree with Lunar Prospector gamma-ray and neutron data which suggest TiO_2 abundance on the order of 1-3% TiO_2 across the plateau (R. Elphic and T. Prettyman, personal communication).

Conclusions. The spectral properties of soils from drive tube 74002 reflect various mixtures of orange glass and black beads. The topmost sample contains minor effects of spaceweathering. The 1µm Fe^{2+} absorption band of the Ti-rich "orange glass" samples measured in reflectance spectra is strongly distorted by the strong Fe-Ti CT bands at shorter wavelengths. Since a symmetric diagnostic Fe^{2+} octahedral band at 1 µm in reflectance data requires glasses that contain little TiO_2, the glass-bearing pyroclastic deposits at Aristarchus must be distinctly low in TiO_2.

Diagnostic features of lunar glasses are very regular (broad band near 1.0µm and weak band near 1.9µm due to Fe^{2+} in octahedral and tetrahedral sites respectively). Materials with these bands require high spectral resolution (hyperspectral) orbiting systems to distinguish them from other lunar compositions (Fig 2). As with Mars, where OMEGA (& soon CRISM) is revealing a new world of martian mineralogy as a result of high spatial resolution hyperspectral data [13,14], a plethora of new discoveries and insights into global lunar mineral properties await the next generation of lunar sensors.

Figure 2. Telescopic Spectra of lunar glass (Aristarchus Plateau), olivine (Copernicus), and basalt (MSA).



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Acknowledgments. NASA support for this research is gratefully acknowledged: NAG5-11763. Reflectance spectra of the lunar samples were measured at RELAB, a multiuser facility operated under NASA grant NAG5-13609.