ANALYSIS OF LUNAR PYROCLASTIC GLASS DEPOSIT FeO ABUNDANCES BY LRO DIVINER.

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Introduction: Telescopic observations and orbital images of the Moon reveal at least 75 deposits, often tens to hundreds of km across, that mantle mare or highland surfaces [1]. These deposits are interpreted as the products of pyroclastic eruptions and designated herein as lunar pyroclastic deposits (LPD). They are understood to be composed primarily of sub-millimeter beads of basaltic composition, ranging from glassy to partially-crystallized [2]. Delano [3] documented 25 distinct pyroclastic bead compositions in lunar soil samples, though the source deposits for most of these beads have not been identified.

The pyroclastic deposits are important for many reasons. Petrology experiments and modeling have demonstrated that the pyroclastic glasses are the deepest-sourced and most primitive basalts on the Moon [4]. Recent analyses have documented the presence of water in these glasses, demonstrating that the lunar interior is considerably more volatile-rich than previously understood [5]. Experiments have shown that the iron-rich pyroclastic glasses release the highest percentage of oxygen of any Apollo soils, making these deposits promising lunar resources [6].

Taurus Littrow: The Taurus Littrow LPD, located in eastern Mare Serenitatis near the Apollo 17 landing site, is both well characterized from orbital data and represented in the lunar sample collection. The deposit covers an area of several thousand km^2 and is approximately ten meters thick [7]. The LPD extends across the Apollo 17 landing site, and the Shorty Crater orange and black glass beads, with an average diameter of 44 μm [7], are understood to be samples of this deposit. Apollo 17 orange and black glasses are identical in major elemental composition, with the color indicating the degree of ilmenite and olivine crystallization following eruption [8].

Diviner Measurements: The Diviner Lunar Radiometer Experiment on the Lunar Reconnaissance Orbiter [9] includes three thermal infrared channels spanning the wavelength ranges 7.55-8.05 μm, 8.10-8.40 μm, and 8.38-8.68 μm. These "8 μm" bands were specifically selected to measure the emissivity maximum known as the Christiansen feature [10]. The wavelength location of this feature, referred to herein as CF, is particularly sensitive to silicate minerals including plagioclase, pyroxene, and olivine – the major crystalline components of lunar rocks and soils. The general trend is that CF positions at shorter wavelengths are correlated with higher silica content and CF positions at longer wavelengths are correlated with lower silica content. Given the range of lunar mineralogy, a direct correlation between CF positions and FeO content is expected (*i.e.* higher CF indicates higher FeO content and vice versa).

Laboratory Spectra: Laboratory thermal infrared reflectance spectra of fifteen Apollo soil samples, characterized in detail by the Lunar Soils Consortium [11,12], were measured under ambient conditions using the FT-IR spectrometer in the Keck/NASA Reflectance Experiment Laboratory (RELAB) at Brown University [13]. Samples in this study are the 20 - 45 μm splits of bulk soil. In addition, the spectrum of sample 74002 – consisting of nearly pure black pyroclastic glass representative of the Taurus Littrow LPD – was measured. The wavelength of the reflectance minimum in the 8 μm region of each spectrum is equivalent to the emissivity maximum, or CF. These CF values are closely correlated to published FeO concentrations for the 20 – 45 μm splits of these soils [11,12] and the pyroclastic glass [3], with an r^2 value of 0.9.

These laboratory spectra are not directly comparable to orbital data, however. Diviner measures emissivity under vacuum conditions, which create a thermal gradient in the uppermost ~200 microns of the surface. Laboratory measurements of pure minerals in a simulated lunar environment (SLE) demonstrate that CF measurements should be modified according to the relationship: CF(SLE) = (CF(lab)-0.6778)/0.9502 [14]. CF(SLE) values derived from the RELAB measurements of the 15 soils and pyroclastic glass remain closely correlated to FeO, with an r^2 value of 0.9. This correlation between CF(SLE) extends across the full compositional range of lunar soils, from FeO concentrations of 4.62 wt. % (soil 61221) to 22.9 wt. % (pyroclastic glass 74002). These results provide a basis for investigating the correlation between lunar soil FeO abundances and CF values derived from Diviner multispectral measurements, and using this correlation to derive the FeO contents of other lunar pyroclastic deposits.

Correlation of Diviner CF with FeO: Diviner CF values, reduced using the most recent corrections of Greenhagen et al. [15], were derived for 2 x 2 km areas centered on each Apollo landing site, as well as the Taurus Littrow LPD. All data were taken near lunar mid-day. These values were plotted against published FeO abundances for the 20 - 45 µm sieve fraction of a characteristic Apollo soil sample from each site [11,12], along with the FeO content of Apollo 17 pyroclastic glass [3]. The CF and FeO values proved to be closely correlated across the full range of Apollo soil compositions (Fig. 1).

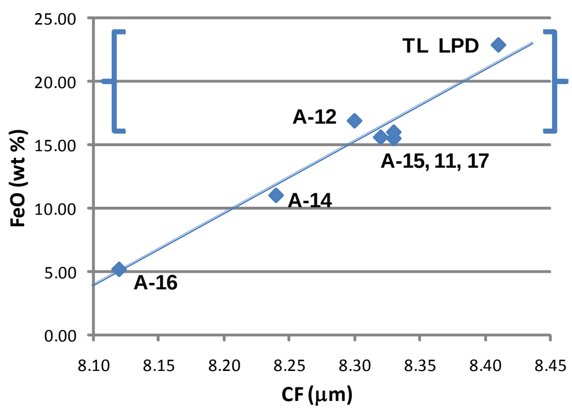

Figure 1. Correlation of Diviner CF values with sample FeO concentrations for the six Apollo sites plus the Taurus Littrow LPD. Brackets denote the full range of pyroclastic glass bead compositions [3].
Regression line: FeO = 61.1 x CF – 492.6 $r^2 = 0.9$

This correlation provides the opportunity to estimate the FeO concentration of other LPD's. These estimates can be compared to the known compositions of pyroclastic glass beads in lunar soils.

Sulpicius Gallus: The Sulpicius Gallus LPD, spanning the mare-highland boundary on the western edge of Mare Serenitatis, contains local concentrations of red and orange material thought to be pyroclastic glass [8]. The Sulpicius Gallus LPD has a higher albedo than the Taurus Littrow LPD, suggesting differing average compositions or differing degrees of crystallization [16,17].

Diviner data, averaged over 2 x 2 km areas on the Sulpicius Gallus LPD, consistently yield maximum CF values of 8.37 µm. This CF value is lower than the value of 8.41 µm that characterizes the Taurus Littrow deposit.

Inserting a CF value of 8.37 µm into the correlation formula shown in Fig. 1 yields an FeO abundance of 18.9 wt. %. This value is significantly below the FeO abundances of orange and black glasses found in the Apollo 11, 14, 15 and 17 soils, but well within the range of the very low titanium and green glasses in soils from the Apollo 14, 15, and 17 sites. [3]. These data indicate that the albedo differences between the Sulpicius Gallus and Taurus Littrow LPD's are due to differing average compositions, rather than to differing degrees of crystallization.

Aristarchus: This LPD spans most of the large Aristarchus plateau, located in Oceanus Procellarum. The deposit displays a range of pyroclastic glass concentrations and spectral signatures, possibly from mixing with underlying material due to cratering [16,17]. The CF value from one of the most glass-rich areas is 8.40 µm, implying an FeO concentration of 20.6 wt. %. This value is close to the FeO concentration of Taurus Littrow glass (22.9 wt. %).

Implications: This work demonstrates that:

- Laboratory CF values, corrected to correspond to a simulated lunar environment, are closely correlated with FeO abundances across the full range of Apollo soils and pyroclastic glasses.
- Diviner CF values are also closely correlated with FeO abundance across the full range of Apollo soils and pyroclastic glasses.
- Diviner CF values have the potential to provide remote analyses of FeO concentrations in previously unsampled lunar pyroclastic deposits.
- Diviner CF values have the potential to provide remote analyses of FeO concentrations across the entire lunar surface.

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