REMOTE ANALYSIS OF REGIONAL LUNAR PYROCLASTIC DEPOSITS – CONSISTENCY AND PRECISION OF LRO DIVINER ESTIMATES.

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Introduction: Allen et al. [1] recently published a new method of estimating the FeO abundances of lunar pyroclastic deposits. This method is derived from orbital thermal infrared measurements by the Diviner Lunar Radiometer Experiment on the Lunar Reconnaissance Orbiter (LRO) spacecraft. The present study utilizes Diviner data from the Taurus Littrow regional pyroclastic deposit to assess the consistency and precision of such estimates.

Lunar Pyroclastic Deposits: Telescopic observations and orbital images of the Moon reveal at least 75 lunar pyroclastic deposits, interpreted as the products of explosive volcanic eruptions [2]. The deposits are understood to be composed primarily of sub-millimeter beads of basaltic composition, ranging from glassy to partially-crystallized [3]. Delano [4] documented 25 distinct pyroclastic bead compositions in lunar soil samples, with a range of FeO abundances from 16.5 - 24.7 wt%.

The Taurus Littrow regional pyroclastic deposit, located in eastern Mare Serenitatis, extends across the Apollo 17 landing site. The Shorty crater orange and black glass beads, with an average diameter of 44 µm [5], are understood to be samples of this deposit. The orange and black glasses are identical in major elemental composition, with the color indicating the degree of ilmenite and olivine crystallization following eruption [6].

Diviner Lunar Radiometer Experiment: Diviner is a near- and thermal-IR mapping radiometer on LRO, with a 320 m (in track) by 160 m (cross track) detector field of view at an altitude of 50 km [7]. Three channels centered near 8 µm are used to measure the emissivity maximum known as the Christiansen feature (CF) [8]. Diviner CF wavelength values, taken from data obtained near local noon, were reduced using the most recent corrections of Greenhagen *et al*. [9]. These corrected CF values are particularly sensitive to silica polymerization in minerals including plagioclase, pyroxene and olivine. Given the restricted mineralogy of most lunar samples, CF values are closely correlated to major element abundances, particularly FeO.

Corrected CF values were determined for five Apollo landing sites (excluding Apollo 14) as well as a dark area on the Taurus Littrow deposit. These averaged values were plotted against published FeO abundances for Apollo soil samples, along with Apollo 17 pyroclastic glass. The CF and FeO values closely correlate across the full range of Apollo soil and glass compositions. The published correlation [1] between FeO abundance (wt. %) and CF (µm) is:

$$FeO = 74.24 \times CF - 599.9; \quad r^2 = 0.90$$

Consistency and Precision: This study addresses the consistency of CF values, and the inherent precision of these values, on the Taurus Littrow deposit. This deposit covers several thousand km^2 and is estimated to be at least 10 m thick [5]. Much of the deposit has a significantly lower albedo than the adjacent mare, but some areas of the deposit are partially covered by high-albedo crater ejecta (Fig. 1).

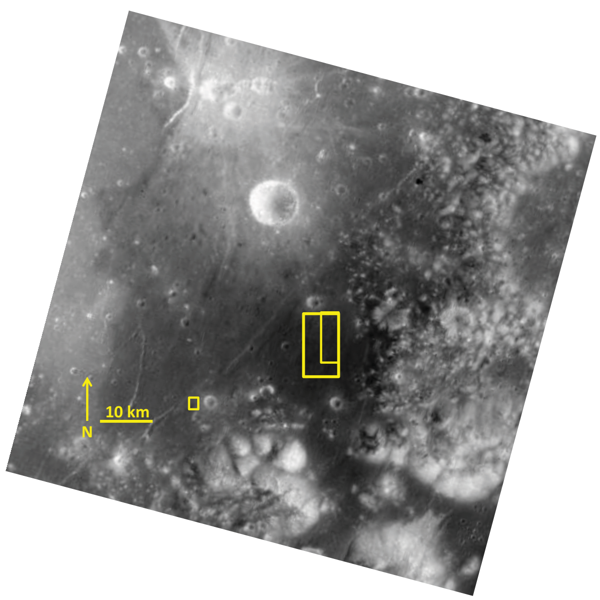

Figure 1. Taurus Littrow regional pyroclastic deposit, with sampled areas outlined (Apollo metric mapping camera image AS15-M-0972)

The initial study [1] included corrected CF data averaged over a 2 x 2 km area centered at 20° 45' N, 29° 21' E (Fig. 1). This area, in the southwest portion of the Taurus Littrow deposit, was chosen for its low albedo. The average CF value was determined to be 8.36 µm, with a standard deviation of 0.03 µm.

Present Study: An area of approximately 20 km^2, bounded by 20.93 to 21.15° N and 30.02 to 30.10° E, was chosen (Fig. 1). This area, in the eastern portion of Taurus Littrow, is within the darkest area of the deposit (Figures 2,3). The averaged CF value is 8.37 μm, with a standard deviation of 0.03 μm.

An area of approximately 50 km^2, bounded by 20.88 to 21.15° N and 29.93 to 30.91° E, was also chosen (Fig. 1). This area includes the 20 km^2 area (above). The larger area is dominated by low albedo material, but also includes limited areas of higher albedo, likely from crater ejecta. The average CF value is CF value is 8.36 μm, with a standard deviation of 0.05 μm.

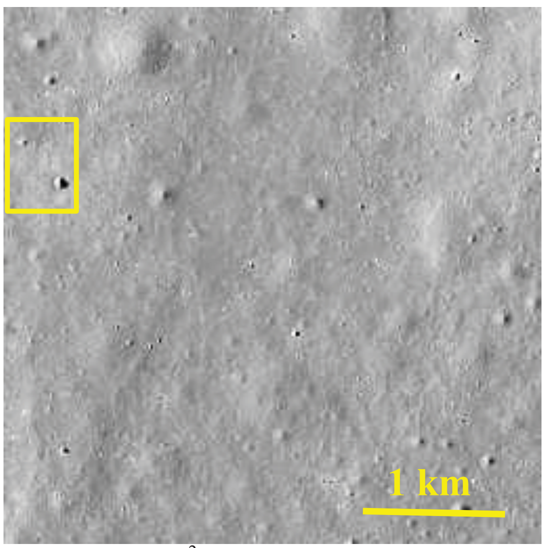

Figure 2. 15 km^2 area of eastern Taurus Littrow pyroclastic deposit (LROC NAC image; area of Figure 3 outlined)

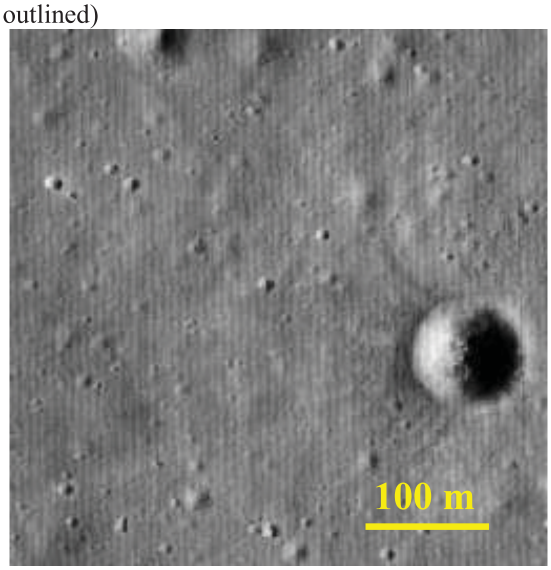

Figure 3. Area of eastern Taurus Littrow pyroclastic deposit, inset in Figure 3 (LROC NAC image)

Discussion: CF values can be affected by changes in viewing/illumination geometry, local topography, albedo, and/or composition [8]. In the present study only data taken near noon was used to minimize changes in viewing and illumination. Regional pyroclastic deposits are large and generally smooth at the scale of Diviner "pixels". Uniformly dark deposits were selected for analysis. Corrected CF values, averaged over areas of 4, 20, and 50 km^2 on two of the darkest parts of the Taurus Littrow deposit, are indistinguishable within one standard deviation. This consistency suggests that the deposit is generally homogeneous over large areas. Therefore, this deposit provides a well-constrained "test case" for determining the precision of Diviner CF measurements.

The CF values averaged over low albedo 4 and 20 km^2 areas have identical standard deviations of 0.03 μm. These standard deviation values reflect both the absolute precision of the Diviner CF derivations (<0.02 μm), as well as the physical and mineralogical variability of the pyroclastic deposits [1]. As shown in Figs. 2 and 3, the Taurus Littrow deposit is strikingly smooth and uniform when averaged over tens of km^2, with a low areal density of craters at the 100 m scale of individual Diviner "pixels".

The standard deviation of CF values averaged over a 50 km^2 area is 0.05 μm, which is significantly greater than the inherent precision of 0.03 μm. Subtle differences in albedo, attributable to impact crater ejecta, are likely reflected in this wider range of CF values.

Conclusions: A standard deviation of approximately 0.03 μm represents the inherent precision of averaged Diviner CF values for pyroclastic deposits. This value corresponds to a precision of approximately 2.2 wt. % FeO. Higher standard deviations of averaged data on pyroclastic deposits likely indicate inhomogeneities in viewing/illumination geometry, local topography, albedo, composition, or a combination of these factors.

References: [1] Allen C.C. et al. (2012) *JGR, 117,* E00H28, doi:10.1029/2011JE003982. [2] Gaddis, L.R. *et al.* (2003) *Icarus, 161,* 262. [3] Pieters, C.M. *et al.* (1974) *Science, 183,* 1191. [4] Delano, J. (1986), *Proc. LPSC, 16th,* D201-D213. [5] Heiken, G. *et al.* (1974) *Geochem. Cosmochim. Acta, 38,* 1703. [6] Weitz, C.M. *et al.* (1999) *Meteorit. Planet. Sci., 34,* 527. [7] Paige, D.A. *et al*. (2009) *Space Sci. Revs*, DOI 10.1007/s11214-009-9529-2. [8] Greenhagen, B.T. *et al.* (2010) *Science, 329*, 1507-1509. [9] Greenhagen, B.T. *et al.* (2011) *42nd LPSC, Abs. #2679*.