CRATERS AS INDICATORS OF COMPOSITIONAL STRATIGRAPHY IN MARE TRANQUILLITATIS AND SERENITATIS Matthew I. Staid and Carle M. Pieters, Department of Geological Sciences, Brown University, Providence, RI 02912

INTRODUCTION Spectrally distinct mare deposits within the Tranquillitatis and Serenitatis basins exhibit a complex sequence of basalt emplacement representing a detailed record of lunar volcanism on the eastern limb [1, 2]. High spatial resolution ultraviolet-visible (UVVIS) Clementine imagery has been used to investigate the spectral properties of mare craters whose deposits suggest the excavation of compositionally distinct subsurface units. Previous interpretations of such spectrally anomalous crater materials have been hampered by the lack of diagnostic information to distinguish immature basalt regoliths. Clementine data and coordinated sample analyses are combined to investigate the stratigraphic implications of such crater materials. Results provide insight into the sequence of basalt emplacement within the two adjacent basins as well as initial investigations into the spectral properties of freshly exposed mare materials.

REMOTE SENSING OF MARE BASALTS The lunar basalts of the Tranquillitatis and Serenitatis basins have been characterized based on empirical relationships between mature mare soils, titanium content [3] and mafic composition [*4*]. In a recent study of Tranquillitatis, Melendrez et al. [5] identified spectrally redder basalts underlying younger bluer, higher titanium units. Using Galileo and Clementine data, Staid et al. [6] further separated these color variations into four major stratigraphic units that increased in titanium content with subsequent basalt emplacement. Finally, Bell and Hawke [7] conducted high spectral resolution studies of mare craters along the Tranquillitatis-Serenitatis border region and discussed the stratigraphic implications of associated materials. Though many important sites of stratigraphic interest lie within and around non-mature mare surfaces, the widely used empirical relations for the interpretation of mare materials are based on the reflectance properties of *mature* soils. Important non-mature sites include spectrally distinct deposits associated with relatively young impact craters and notable variations along the sloped walls of older craters. The spectral properties of these optically immature materials are likely be more diagnostic of composition than mature soils because their mineral absorptions have not been as severely weakened by space weathering processes [8]. However, the reflectance characteristics of such freshly exposed materials are poorly understood. The low spatial resolution of previous studies have been unable to resolve the spectral properties of craters small enough to have sampled individual basalt flows which are relatively thin [9,10] or fresh exposures of basaltic materials along crater walls [11].

CLEMENTINE UVVIS IMAGERY High resolution Clementine data is used to characterize the spectral properties of homogeneous and optically fresh lunar materials associated with small (< 2 km) mare craters. This information is then applied to the interpretation of immature deposits associated with larger craters which may have excavated compositionally distinct subsurface units. The five filter Clementine UVVIS imagery requires extensive processing after decompression to produce multispectral image mosaics [12,13]. Calibrated reflectance data for selected sites within the Tranquillitatis and Serenitatis basins are presented in figure 1. Reflectance spectra obtained from representative small and optically immature mare craters (S_f, figure 1a) within Serenitatis' low titanium mare display a diagnostic red ultraviolet to visible slope which is slightly redder than mature Serenitatis soils (S_{mat}) and strong absorption features around 1 μm. By comparison, Clementine reflectance spectra of very fresh deposits within the high titanium basalts of Tranquillitatis (T_f) exhibit bluer ultraviolet to visible slopes similar to mature Tranquillitatis soils (T_{mat}) and more subdued 1 μm absorption features. The consistency of this pattern in many spectra of the brightest and presumable youngest mare craters suggests that these spectral characteristics are related to the compositional properties of relatively unweathered basaltic materials. Laboratory spectral reflectance studies of lunar basalt chips and powders are currently being conducted to determine the absorption features responsible for these characteristics. Initial laboratory results are consistent with the observation that optically immature titanium rich basalts are bluer than low titanium basalts and have more subdued pyroxene absorptions around 1 μm.

APPLICATIONS TO BASALT STRATIGRAPHY Previous spectral studies of northern Tranquillitatis [5,6,7] suggest that anomalously low UV/VIS ratio values west of the crater Dawes (18 km) may be related to the excavation of a compositionally distinct subsurface unit during an oblique impact. Based on regional stratigraphy, it has been suggested these materials may represent an underlying layer with a lower titanium content [5,14], however compositional interpretation of such materials based on the Charette relation are not valid because 1 μm absorption features indicate that Dawes ejecta are relatively immature [7] and reflectance features of mature and immature soils cannot be compared directly. The high spatial resolution Clementine UVVIS reflectance data presented in figure 1b confirm the presence of two compositionally distinct units within freshly exposed wall materials of Dawes and in the surrounding ejecta deposits. Spectra of dark wall materials ($D_{f\ blue}$) related to the talus wasting of a basalt outcrop exhibit spectral properties which are consistent with the fresh high titanium materials presented in figure 1a. Spectra of wall materials which have not been affected by the mass wasting of this basalt exposure ($D_{f\ red}$) are consistent with spectra of fresh low titanium materials. The asymmetric ejecta pattern around Dawes crater [14] also exhibit spectral variations that are consistent with the presence of immature materials with different basaltic compositions. Reflectance spectra for materials at ~1 crater radius east (D_e) and west (D_w) of Dawes are also given in figure 1b. Though this ejecta should have the same maturity state, different UVVIS slopes and 1 μm absorption features are consistent with distinct compositional properties: lower titanium ejecta to the west and higher titanium materials to

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the east. The freshly exposed lower titanium materials along the interior walls of Dawes ($D_{f\ red}$) are very similar to the spectral characteristics of wall materials within the 16 km Serenitatis crater Bessel (B_f, figure 1c). Other spectra taken along Bessel's wall show variations in 1 µm strength and albedo but do not display the distinctive variations in UVVIS slope seen at Dawes. Ejecta surrounding Bessel (B_{be}, figure 1c) appears to be relatively mature and are slightly bluer than surrounding units (B_m). These spectral characteristics suggest the excavation of a unit slightly richer in titanium content than surrounding mare and similar to basalts in southern Serenitatis (S_{mat}).

DISCUSSION Clementine ultraviolet to visible reflectance spectra indicate that freshly exposed lunar basalts display diagnostic spectral properties related to composition and titanium content. Diverse optically immature deposits at the mare crater Dawes exhibit spectral properties that distinguish between compositional variations and maturity. These data substantiate previous suggestions of the excavation of a lower titanium subsurface unit from beneath high titanium surface units [5,14]. The spectral properties of materials surrounding Bessel crater in Serenitatis are also consistent with the excavation of a compositionally distinct subsurface unit with increased titanium content as suggested by Bell and Hawke [7]. However, Clementine data suggests that the excavated unit in Serenitatis is much closer in composition to overlying deposits than at Dawes.

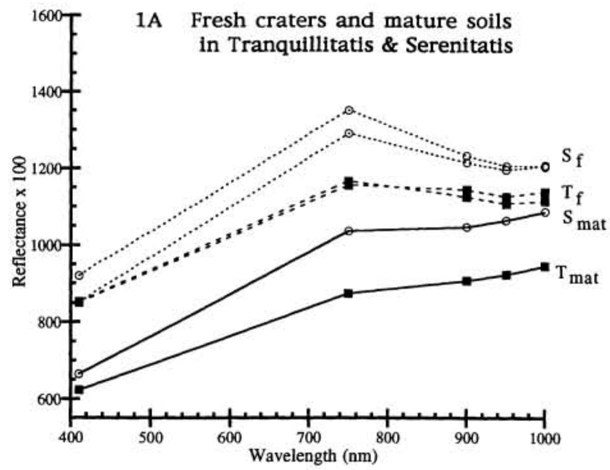
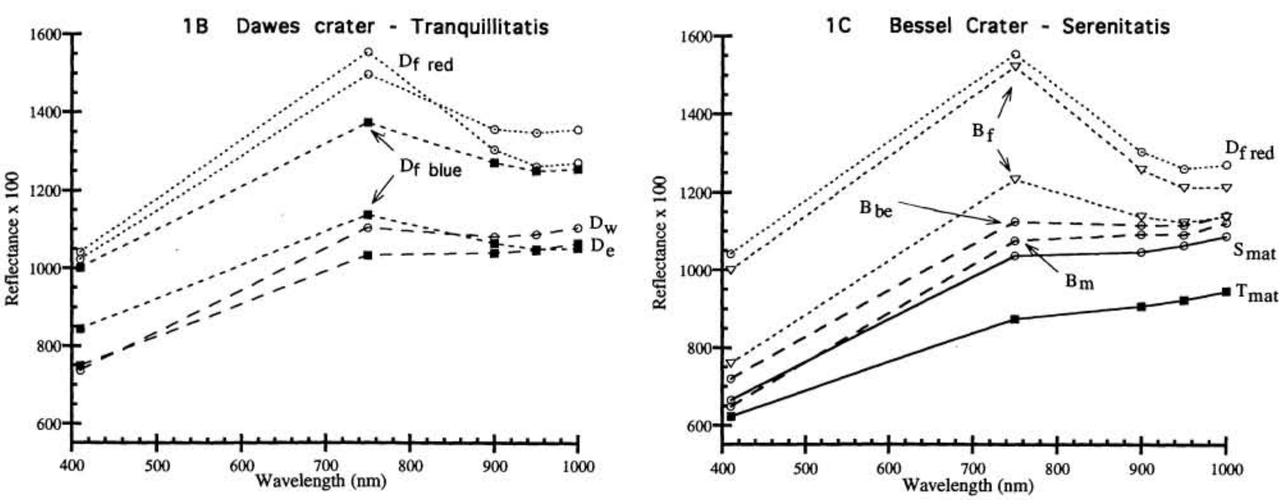


Figure 1 Calibrated Clementine UVVIS reflectance data for selected sites in Tranquillitatis and Serenitatis. Open circles indicate lower titanium materials and filled squares indicate higher titanium deposits. Solid lines represent mature mare soils while heavy dashes represent exterior crater materials and light dashes indicate spectra taken from crater interiors.



References: **1)** Pieters, C.M. (1978) *LPSC 9th*, 2825-2849 **2)** Wilhelms, D.E. (1987) USGS Prof Paper no. 1348. **3)** Charette, M.P. et al. (1974), *JGR*, 79, 1605 **4)** Pieters C.M. and McCord, T.B. (1976) *LPSC* 7th, 2677-2690 **5)** Melendrez, D.E. et al.. (1994), *JGR*, 99, 5601-5620 **6)** Staid M.I. et al. *JGR* in review **7)** Bell, J. and B.R. Hawke (1995) *Icarus* 118, 51-68 **8)** Fischer, E.M. (1994) *Icarus*, 111, 475-488 **9)** De Hon, R.A. (1974) *LPSC 5th*, 53-59 **10)** Head, J.W. (1976) *Rev. Geophys. Space Phys.*, 14, 265-300 **11)** Pieters et al., (1993) in *Remote Geochemical Analysis*, Cambridge U. Press, NY, 309-339 **12)** Pieters, C.M. et al. (1994) *Science*, 266, 1844-1848 **13)** Pieters et al. http: //www.planetary. brown.edu/clementine/index.html **14)** Staid, M.I. et al. (1995) *LPSC XXVI*, 1345-1346.