DISTRIBUTION AND GEOLOGIC HISTORY OF MATERIALS EXCAVATED BY THE LUNAR CRATER BULLIALDUS Stefanie Tompkins, Carle M. Pieters, John F. Mustard, Dept. Geol. Sci., Box 1846, Brown University, Providence, RI 02912

Introduction: The crater Bullialdus is a 61 km, Eratosthenian-age impact crater located on the western edge of Mare Nubium. Previous analysis of the spatial distribution of materials in the area using nine telescopic near-infrared spectra suggested a possible three-layer structure prior to the impact event: two shallow gabbroic layers and one deeper noritic layer (from a potential depth of 5.5 km) (1). The initial interpretation of this stratigraphy was that Bullialdus may have tapped a layered mafic pluton, such as have been invoked to explain the existence of Mg-suite rocks (2). High-spatial resolution CCD images of Bullialdus were analyzed to better map the spatial distribution of the observed lithologies, and to assess the plausibility of the pluton interpretation.

Data Processing: CCD images were obtained with a Thomson CCD camera mounted on the 2 m telescope (F/D = 25) of the Pic du Midi Observatory. Image dimensions were 194 pixels by 281 lines. Eight spectral images were used at 0.40, 0.56, 0.73, 0.91, 0.95, 0.98, 0.99, and 1.02 μm. Images taken at 0.73 μm and longer wavelengths were calibrated to telescopic spectra (1) using an empirical line method (3). Images obtained at 0.40 and 0.56 μm were calibrated using similar Galileo image data (4) but the accuracy of these spectral calibrations may be lower due to the lower DN values and spatial resolution for Galileo. A linear mixing model was initially used to evaluate the distribution of spectroscopically distinct materials across the crater. In this approach (5, 6), small areas thought to represent distinct lithologies are chosen within the image. The spectral properties of these representative "end-members" are combined in a least-squares mixing algorithm to provide the best fit for each pixel within the image. (For a discussion of objectively identifying and characterizing end-members, see (7)). Images mapping the fractional abundance of each end-member show their spatial distribution. These fractional abundances are constrained to sum to 1.0 for each pixel, and the average fitting error is less than 2%. Surface units can be mapped based on the relative proportion of materials present. Shown in Figure 1 is a map of the distribution of lithologic units based on the spectral mixture model results. Calibrated spectra of end-members are shown in Figure 2.

Discussion: Analysis of the fraction images clearly indicates the western portion of the central peaks (End-member 1) as a localized unit within the crater. From the previously obtained near-infrared spectra (1), the central peaks are interpreted to be anorthositic norite. The remainder of the peaks and part of the floor are a distinctly different unit (End-member 2), with a shallower 1-μm absorption. This distinction can be clearly seen in the end-member spectra (Figure 2). End-member 2 is interpreted to be a second noritic unit, but with a lower abundance of pyroxene relative to plagioclase than End-member 1, comparable to noritic anorthosite. The spatial resolution of the near-infrared spectra is much lower than for the CCD images, and the noritic spectrum identified by (1) was a mixture of these two end-members. End-member 3 includes both wall and rim material, interpreted to be gabbroic in composition (1), with a longer wavelength 1-μm absorption and a relatively immature spectral slope. The small difference in absorption band positions observed previously between the wall and rim near-infrared spectra (1) is not detectable within the spectral range of the CCD images. Relative freshness of the gabbroic materials is distinguished by End-member 4 (associated with the low-albedo area surrounding the crater). This end-member appears to represent mature, well developed gabbroic soils, with the same long wavelength 1-μm absorption as End-member 3, and a redder slope than the other end-members.

Stratigraphy: The surface distribution of materials can be combined with a knowledge of impact cratering dynamics (e.g. 8) and general lunar history (9) to predict the pre-impact stratigraphy beneath Bullialdus. Figure 3 presents a possible cross-section. From top to bottom, the stratigraphic units are: a thin layer (250-500 m) of mare basalt (10), Imbrium and Humorum ejecta (total thickness estimated to be less than 600 m) (11), two types of gabbroic material, and two types of noritic material (noritic anorthosite and anorthositic norite). The upper two layers are inferred from geologic context, but are not observed from the spectral data. The central peak end-members appear to be confined to their respective halves of the crater floor. There are several interpretations for these two central peak units. If the central peaks were derived from the same depth, their compositional distinction suggests that the two units either were one continuous layer with a lateral change in composition, or that they occurred as two dipping layers. A graben has been mapped that occurs along the contact between the two central peak noritic compositions (12). This graben suggests the central peak compositions occurred separately and would support a model with two separate layers. The direction of dip is not clear, however: the observed distribution could be caused be eastward dipping layers with End-member 2 above End-member 1, or westward dipping layers with 1 above 2.

Possible Interpretations and Implications: The existence of pre-impact layered units with distinct mafic mineral compositions is clear, but the origin of these layers is not uniquely determined. The original layered mafic pluton theory is still viable, although such a pluton would have to post-date or survive the basin-forming events of the area. Another possibility is that the gabbroic material seen at Bullialdus is derived from basalt from older flows within Mare Nubium that pre-date the Humorum and Imbrium basin-forming events, and that the noritic central peaks are sampling the Nubium Basin floor. Alternatively, the geologic setting at Bullialdus provides a possible source for a large differentiated melt sheet. Investigations of the Sudbury Impact indicate that a differentiated impact melt sheet could form within a large impact crater (e.g.13). Bullialdus lies near the center of the 420-km-diameter pre-Nectarian Western Nubium Basin (9, 10). As the Western Nubium Basin could have had a melt sheet approximately 3.5 km thick, a layered mafic body may well exist beneath Bullialdus of an origin similar to that hypothesized for Sudbury. If a differentiated impact melt sheet or pluton was formed in the Nubium Basin, layered sequences could be expected at other basins. A more detailed study of craters in a similar geologic context to Bullialdus (e.g. Copernicus) should be undertaken to examine this possibility.

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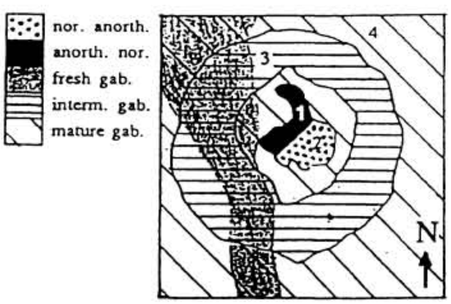

Figure 1: Map of lithologic units seen in spectral mixture model results for the 61 km crater Bullialdus. Numbers indicate location of spectra shown in Figure 2.

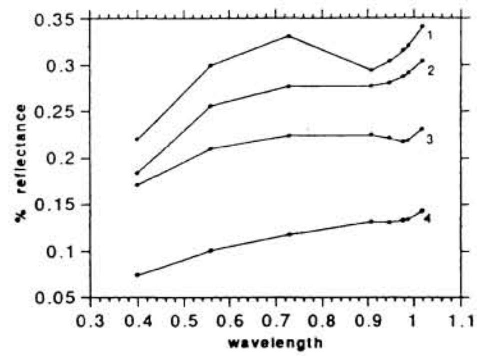

Figure 2: End-member spectra (for locations see Figure 1).

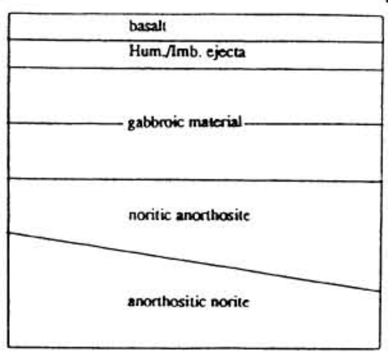

Figure 3: Cross section of possible pre-impact stratigraphy.