Bullialdus Crater: Probing Mineralogy and Local Hydroxyl Abundance

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Bullialdus Crater

- 20.7°S, 22.2°W on western edge of Mare Nubium
- 61 km diameter
- Eratosthenian-aged
- Central peak nortic, walls more enhanced in clinopyroxene
- Layered mafic pluton (Pieters, 1991)
- Other possibilities include impact through thin old basalt flows, or through a differentiated melt sheet from the Nubium impact (Tompkins et al., 1994).
- Radiative transfer modeling suggests immature regions of the peak range from anorthositic norite, anorthositic gabbronorite to norite (Cahill and Lucey, 2007)
- Mean Mg’ 70 (Cahill et al. 2009)
- Norites in central peak modeled to be >Mg’ 75 (Klima et al. 2011).
M³ Data:
Color Composites

- **M³ standard color composite:**
  Red = Integrated 1 µm band depth
  Green = Integrated 2 µm band depth
  Blue = Reflectance at 1.58 µm
  Highlands Blue, Pyroxene Yellow

- **Pyroxene composite:**
  Red = 1.9 µm band depth
  Green = Integrated 2 µm band depth
  Blue = Integrated 1 µm band depth
  Highlands Black, LCP Yellow, HCP Cyan
Lunar Mineralogy: A Hyperspectral View

Moon Mineralogy Mapper (M³)
Vis-NIR Imaging Spectrometer

Global Mode:
85 bands

20-40 nm spectral sampling

140 m/pixel at 100 km orbit

0.4-3 um wavelength range
This is a significant effect, especially since this is a systematic effect and will accumulate for features extending over a number of pixels. Finally, we note that the deconvolved map shows high frequency spatial variations that are indicative of noise artifacts.

Figure 1c shows the deconvolution results using the Pixon method. Many of the same features seen in Figure 1b are also seen here, but the reconstructed map is significantly smoother, which is consistent with the goal of finding the simplest image consistent with the data and uncertainties (Puetter et al., 2005). Figures 2b and 3b show the residual map and histogram for the Pixon method. Compared to Jansson's technique, the Pixon residual map is smoother and does not show the same degree of spatial correlation with the original map. The histogram of Pixon residuals shows a mostly Gaussian shape with a width (0.96) that is close to 1 and has an offset that is less than 1% of the standard deviation. This result contrasts to the Jansson histogram, which has a significant negative offset. Both the residual map and histogram show that the Pixon method gives a result that is more consistent with the data uncertainties than is given by the Jansson result. When these criteria are combined with the observation that the Pixon map is markedly smoother than the Jansson map, we conclude that the Pixon technique gives a significantly improved result that is better than the Jansson technique, and that some of the high frequency spatial features seen in the Jansson results are artifacts and not warranted by the data.

4. Full Nearside Map and Discussion

Figure 4 shows a global nearside map where the Th abundances have been deconvolved using the Pixon method. This map was constructed using regions (i.e., equivalent size at the equator) that were combined together to create the map shown. The absolute Th abundances were derived by correlating the deconvolved counting rate with the Th abundances of Prettyman et al. (2006) in a manner similar to what was done for the smoothed Th map of Lawrence et al. (2003).

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Enhanced Thorium detected at Bullialdus corresponds to anorthositic and noritic terrain

Clementine

Lunar Prospector Thorium

M³

M³ Color Composite:
Yellow: Low-calcium pyroxene  Black: Anorthosite
Blue/Cyan/Purple: Mare basalt or enriched in high-calcium pyroxene
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Black: Anorthosite
Blue/Cyan/Purple: Mare basalt or enriched in high-calcium pyroxene
Absorption at 2.8 um: OH$^-$ strongly enhanced only in central peak
View is from North. Color ramp grades from dark blue (low) through white (high) OH$^-$ abundance. High OH$^-$ appears to correlate with higher albedo, more boulder-rich regions of the central peak.
Central peak imaged during three optical periods.

All show OH⁻ band in central peak.
Typically, non-polar OH\textsuperscript{-} is likely to be present as a thin surficial layer, likely produced by interactions of the solar wind with the lunar regolith (e.g., Pieters et al., 2009; Sunshine et al., 2009).

Bullialdus was fully imaged by M\textsuperscript{3} at three different times in the lunar day. The 2.8 um absorption is observed and is of roughly equivalent strength during all of them.

Highlands soils typically exhibit stronger OH\textsuperscript{-} bands, but those surrounding Bullialdus show little to no absorption.

Fresh craters are observed to exhibit stronger OH\textsuperscript{-} bands, potentially due to an abundance of fractured bonds facilitating in-situ OH\textsuperscript{-} production. Bullialdus central peak is relatively immature due to mass wasting, but not freshly impacted.
Bullialdus Crater: KREEP, Norite and OH⁻

- While the region surrounding Bullialdus is enhanced in thorium relative to the bulk Moon, there is a ‘hot spot’ associated with Bullialdus.

- Noritic and anorthositic material within ±10 degrees N and E of Bullialdus also correlates with enhancements in thorium.

- ‘Normal’ highland anorthosites SW of Bullialdus do not correlate with enhanced thorium.

- OH⁻ is enhanced only in the central peak.

- Position of OH⁻ band is consistent with OH⁻ in pyroxene or other silicates, but low spectral resolution (40nm) makes characterization non-unique.
Bullialdus Crater: Implications

- The mineralogy of the central peak of Bullialdus is consistent with material from a KREEP-rich, Mg- or Alkali-suite pluton. Deconvolved thorium abundance is most consistent with the Alkali suite. If the OH\(^-\) is internal to the rocks, it supports OH\(^-\) enrichment in late stage urKREEP liquids.

- As a mafic pluton, less OH\(^-\) would have degassed than in KREEP-rich basalts.

- Further work is ongoing to characterize the nature of the OH-band in more detail and to place bounds on the amount of OH\(^-\) detected.
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