**Introduction:** Recent data from the Moon Mineralogy Mapper (M3) coupled with elemental data from Lunar Prospector’s Gamma Ray Spectrometer (GRS) provide an opportunity to probe the composition of the lunar surface in great detail. Hyperspectral near-infrared data measure diagnostic mafic absorption bands, which can be used to infer the mineral composition, structure, and in some cases even site occupancy for iron-bearing minerals. Infrared data are also sensitive to vibrational absorptions produced by hydroxyl and water bound within or adsorbed to minerals. We compare the pyroxene mineralogy and relative hydroxyl content of prominent noritic exposures and their association with Lunar Prospector thorium for locations across the Moon.

**Background and Motivation:** Recent studies of lunar water have primarily focused on production of hydroxyl (and/or water) through interactions of the solar wind with lunar soil [1-4], but new evidence suggests that some of the hydroxyl observed from orbit may be magmatic water, bound within the minerals themselves [5]. In the case of Bullialdus crater (Fig. 1), this hydroxyl is found in association with noritic mineralogy, and also coincides with an enhancement in thorium as detected by the Lunar Prospector. These findings indicate that the rocks within Bullialdus crater also likely contain a large amount of potassium, rare earth elements, and phosphorus (KREEP) [5, 6].

The evidence that the rocks in Bullialdus crater are both hydroxyl- and thorium- enriched is contrary to what has been observed in returned lunar samples. Apatites in KREEP-rich rocks from the Apollo samples have been found, in general, to be depleted in hydroxyl, while those in mare basalts exhibit range of compositions, some of which suggest hydroxyl enrichment [7]. We have thus begun investigating other regions throughout the lunar nearside that are enriched in thorium to determine whether they, too, have distinctive hydroxyl anomalies associated with them.

**M3 Data Analysis:** The M3 was a visible-near-infrared imaging spectrometer flown by NASA as a guest instrument on India’s Chandrayaan-1 mission to the Moon [8]. In global mode, data were obtained at 140 m/pixel spatial resolution while the spacecraft was in a 100 km orbit, and at 280 m/pixel while it was in a 200 km orbit. Spectral channels in global mode are binned to a 20-40 nm spectral sampling, with higher spectral resolution covering the 1000 nm region so that mafic absorptions due to olivine and pyroxene can be more accurately measured. Unfortunately, before launch, water/hydroxyl was not anticipated to be a major component of the global lunar surface, so data in the 3000 nm range are binned to a 40 nm resolution, complicating analysis of this feature.

![Image](image_url)

**Fig. 1.** (Left) 2800 nm band depth map displayed as a color ramp (black to red) overlain on a monochrome image of Bullialdus crater. Black regions, which exhibit no 2800 nm band, have been changed to transparent in this overlay. (Right) example spectra from Bullialdus central peak, rim, and two mature soils outside of the crater. The second soil spectrum was extracted from a mature highlands location roughly 100 km south of Bullialdus crater.

**Regional Comparisons:** We focus here on comparing the Aristarchus and Aristillus regions with Bullialdus crater, as they are both enhanced in thorium and located at moderate lunar latitudes. This comparison helps to mitigate interference with surficial hydroxyl/water adsorption.

An image matrix depicting different measurements of the Bullialdus (20.7°N, 22.2°W), Aristillus (33.9°N, 1.2°E) and Aristarchus (23.7°N, 47.4°W) craters is presented in Fig. 2. Morphologically and mineralogically, Aristillus is more similar to Bullialdus than is Aristarchus. Both Bullialdus and Aristillus central peaks are dominated by norite, though orthopyroxene at Aristillus is modeled to be more iron-rich than that at Bullialdus [9]. The thorium anomaly over Aristillus (~12ppm) is stronger than in the Bullialdus region (~6-8ppm)[10]. Unlike Bullialdus, however, there is no hydroxyl anomaly associated with Aristillus crater. Taken together, evidence from the two data sets suggests that Aristillus central peak may have excavated material similar to alkali-suite norites found in the Apollo collection. At Aristarchus, a larger variety of minerals are excavated, as detailed by Mustard et al. [11]. The southern rim of Aristarchus is slightly en-
hanced in hydroxyl, and this enrichment seems to be associated with predominately anorthositic and olivine-rich material. The diffuse nature of this enrichment makes it difficult to distinguish whether it is intrinsic to the local rocks, or a later accumulation of surface hydroxyl adsorbed to the southern portion of the crater.

Implications: Combined studies of thorium abundance, mineralogy, and hydroxyl abundance provide a powerful method to probe the composition of the lunar crust. We are expanding this study and beginning to incorporate further constraints on composition and hydration using neutron measurements.

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Fig. 2. Comparison of three craters with thorium anomalies (top-Bullialdus; middle-Aristillus; and bottom-Aristarchus). The left column presents a context image of the region, extracted from the Wide-Angle Camera (WAC) mosaic of the lunar nearside, produced by the Lunar Reconnaissance Orbiter Camera (LROC) team (credit: NASA/GSFC/Arizona State University). The second column presents the thorium abundance as measured by Lunar Prospector (LP) (modified from Lawrence et al. [11]). The third column presents the standard M^3 color composite, where the integrated 1000 nm band depth is displayed in the red channel, the integrated 2000 nm band depth is displayed in the green channel, and the reflectance at 1500 nm is displayed in the blue channel. In this depiction, olivine-enriched deposits appear as red or pink, orthopyroxene and noritic materials generally appear as cyan, clinopyroxenes or pyroxene mixtures appear as oranges and yellows, and anorthosite appears as blue. In the fourth column, a color composite that is designed to highlight the differences in pyroxene mineralogy is presented. The red channel displays the 1900 nm band depth, the green channel displays the integrated 2000 nm band depth, and the blue channel displays the 1000 nm band depth. In this depiction, featureless spectra (both anorthosite-dominated and very optically mature) appear as black, olivine-enriched material appears as deep blue, clinopyroxene-rich material appears as cyan, and orthopyroxene dominated material appears as yellow. Soils with a small component of orthopyroxene as well as pyroclastic glasses appear as pink. The fifth column depicts the continuum-removed ‘hydroxyl’ band depth at 2800 nm.