NEW ESTIMATES OF THORIUM ABUNDANCES FOR THE RIMA BODE PYROCLASTIC GLASS DEPOSIT

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Introduction: The Rima Bode pyroclastic glass deposit is thought to consist almost entirely of ilmenite-rich, black, volcanic glass [1,2], which has led some workers to suggest that Rima Bode is a prime target for resource utilization [e.g., 3]. In addition to its resource potential, the Rima Bode deposit has two critical characteristics that can be utilized to provide scientific information about this region of the Moon: (1) remote sensing data indicate that the Rima Bode deposit is rich in thorium (Th), an element whose abundance is vital to understanding the thermal evolution of the Moon [4]; (2) like other pyroclastic glasses, the Rima Bode glasses are the best examples of primitive volcanic materials, and therefore are of critical importance in characterizing the lunar interior [5,6,7,8].

While Th data from the Lunar Prospector Gamma Ray Spectrometer (LP-GRS) indicate that the Rima Bode deposit is Th-rich (Figure 1), it should be noted that the deposit is located adjacent to several other Th-rich features. Therefore, it is possible that a low-Th signature at Rima Bode is being overwhelmed by the adjacent high-Th sources. In an attempt to better understand the Th distribution at Rima Bode, we have used Th data from the LP-GRS, along with a variety of other remote sensing data, to construct a forward model that allows us to estimate the Th abundances of specific portions of the deposit. The new Th distribution map not only provides compositional constraints on the Rima Bode pyroclasitc deposit, but also provides information about the magmatic evolution of this portion of the Moon.

Rima Bode Background: The Imbrian-aged Rima Bode pyroclastic deposit is located in the central portion of the lunar near side [12°N, 357°E] superimposed on highlands between Sinus Aestuum and Mare Vaporum [1,2,7]. The Rima Bode deposit consists of 10-20 meters of loose, unconsolidated, fine-grained, volcanic material covering an area of 6,620 km^2 [1,2,3,7]. The underlying highland terrain contains hummocks and lineations consistent with the Th-rich Imbrium ejecta deposit [1,2,9,10,11], suggesting that the Th-rich ejecta is the major source of Th in the region.

In addition to being underlain by Th-rich lithologies, the Rima Bode deposit is surrounded by Th-rich features including the southeastern rim of the Imbrium basin, the southern tip of Montes Apenninus, and Th-rich ejecta from Copernicus crater. Being located in a Th-rich environment has led to uncertainty about the true Th content of the Rima Bode deposit. However, we can resolve this uncertainty by using forward modeling of Th abundances in the region to estimate the Th content of the thickest, least contaminated portion of the deposit, which in turn will provide the clearest compositional information about the Rima Bode deposit [e.g., 12].

Forward Modeling: As part of our forward modeling process, we re-create a portion of the lunar surface in which we can control the Th abundances of specific geologic features [e.g., 13]. We select our regions of interest by using a combination of existing geologic maps, orbital photography, spectral reflectance data, and gamma-ray and neutron data [e.g., 12,13]. We use these data to define specific geologic features and lithology types. We are aided in this effort by previous investigations of the Rima Bode deposit [e.g., 1,2,7] that have already defined major geologic units in the region. These studies show that the thickest, darkest part of the pyroclastic deposit (unit A of [2]) does not appear to have been affected by contamination from other materials [2,14]. Perhaps more importantly, the possibility of horizontal mixing in this region is limited by the sharpness of the contacts between the various units [2,14], indicating that the Rima Bode deposit consists only of volcanic materials.

Once we have identified specific geologic units in our model, we assign Th abundances to each of those units using the procedures outlined in our previous work [12,13,14]. We then propagate the expected gamma ray flux from these geologic features through the LP-GRS spatial response, which produces a simulated Th distribution. We then compare the simulated Th distribution to the measured Th data and iteratively adjust the simulated distribution until we achieve a match with the measured data. Once a match is achieved, we can use the modeled Th distribution to determine the Th abundance of any given feature of interest. We recognize that this procedure gives a non-unique result; however, we obtain quantitative estimates and uncertainties of surface abundances using a chi-square (χ^2) minimization technique [e.g., 15] that compares the measured and modeled Th abundances.

Results and Conclusions: A comparison of the LP-GRS Th map (Figure 1) with our forward modeling results (Figure 2) shows that our modeled abundance distribution closely matches the measured Th distribution. Figure 3 shows that Th abundances lower than 5 ppm are not consistent with the measured data (i.e., Rima Bode must have ≥ 5.0 ppm). A χ^2 analysis of our modeled results shows that the uncontaminated portion of the deposit (black outline in Figures 1 and 2), is consistent with a Th content of 5.05 ± 0.40 ppm. A complementary deconvolution method (i.e., the Pixon method [16]), shows that the uncontaminated portion of the deposit is consistent with a Th abundance of ~5.50 ppm. In total, our results show that the elevated Th abundances at Rima Bode are inherent to the pyroclastic deposit and are not the result of being co-located with other Th-rich sources. We can use this robust Th estimate, in conjunction with other remote sensing data, to place additional constraints on the composition and petrogenesis of this volcanic deposit.

Examination of other LP and Clementine data sets shows that the titanium (TiO_2) abundances at Rima Bode vary from ~10 wt.% (LP-GRS) to ~14 wt.% (Clementine) TiO_2, while iron (FeO) abundances range from ~18 wt.% (LP-GRS) to ~22 wt.% (Clementine). These TiO_2 and FeO values are consistent with measured abundances in red-black glasses from the lunar sample suite [6], a result that is consistent with previous suggestions that the Rima Bode deposit is indeed composed of ilmenite-rich black glasses [2,7]. Additional support for this assertion can be derived from a comparison of our modeled Th values with Th values in the lunar sample suite, which shows that a Th abundance of 5.0 ppm is consistent with Th abundances in Apollo 14 (A14) red-black glasses, which have an average of 5.0 ppm Th [8].

In summary, the results from this study can be used to suggest that the Rima Bode pyroclastic glass deposit contains elevated Th abundances and that the glasses in the deposit are compositionally similar to the A14 red-black glasses. As is the case for glasses in the sample suite, it is likely that the elevated Th abundances in the Rima Bode deposit represent the incorporation of a Th-rich component into the parental magmas. The mechanism by which a Th-rich component was incorporated is debatable. However, the rapid ascent of pyroclastic magmas on the Moon [17], tend to indicate that the Th-rich component was not added via assimilation but was inherent to the source region, as was suggested in the petrogenetic models for the A14 red-black glasses [6,8]. If true, these results could be used to suggest that both the crust and the underlying mantle at Rima Bode are rich in Th and that the thermal driver for extended volcanism at Rima Bode was the decay of heat-producing elements in the underlying lunar mantle.

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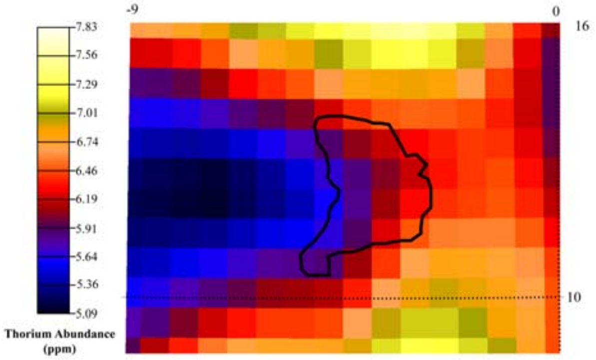

Figure 1. LP-GRS Th abundance map for Rima Bode. The area outlined in black represents the portion of the pyroclastic deposit that contains minimal contamination from adjacent Th-rich sources.

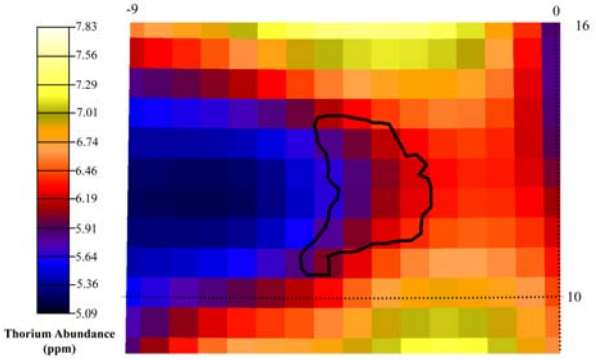

Figure 2. Forward modeling results for Rima Bode. The area outlined in black represents the portion of the pyroclastic deposits that contains minimal contamination from adjacent Th-rich sources. The selected region has 5.05 ppm Th.

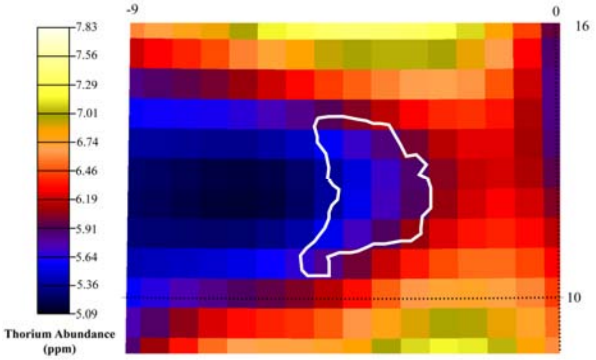

Figure 3. Forward modeling result if the uncontaminated portion of Rima Bode (outlined in white) has 4.0 ppm Th instead of 5.0 ppm.