CORRECTING IMPACT MIXING REVEALS UNDERLYING GRAIN DENSITY IN THE LUNAR CRUST.

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Motivation: Grain density is an important input parameter to the derivation of porosity from gravity analyses. For example, the high resolution data derived from Gravity and Recovery Interior Laboratory (GRAIL) [1] have been used to derive the crustal porosity by comparing bulk density estimates to estimates of grain density in the lunar crust [2,3]. Iron and titanium oxide abundances retrieved from Lunar Prospector Gamma-Ray Spectrometer (LP-GRS) and measured from in-situ returned samples are utilized to derive this observed grain density [4]. Although the derived grain density using LP-GRS data for the lunar crust is closer to the true grain density of the underlying crust than the estimate from the visible spectral reflectance data, the ≤1 meter deep column of the lunar regolith is well-mixed products of variety of materials [e.g., 5]. The main goal of the study is to recover a true grain density of a underlying crust in the most pristine highlands, the lunar northern central farside.
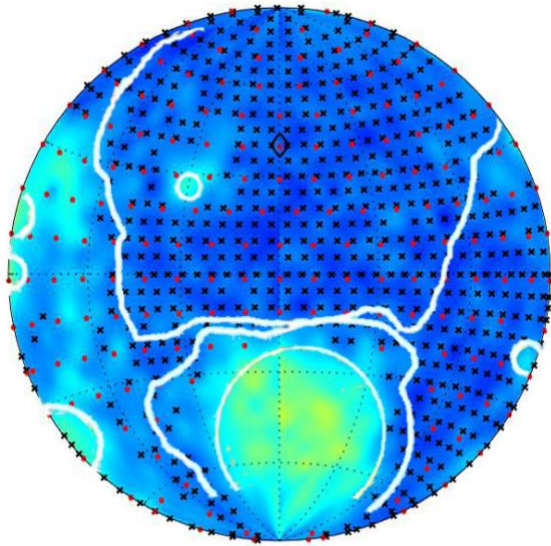

Figure 1: Global lunar iron oxide abundance map by LP-GRS. The white contours are directly taken from the contours for the three major lunar terranes (FHT, SPAT, and PKT) proposed by Jolliff et al., [6]. The contours above SPAT (yellow blue color on the south pole of the Moon - SPAT) is defined as Feldspathic Highland Terrane (Anorthositic) (FHT, An) in [6]. The black data points represent the locations of 5 degree LPGRS data, and the red data points represent the location that the observed porosity is derived [3]. We use azimuthal equal-area projection centered at latitude of 0° and longitude of 180°E with a radius of 90° [7].

Data analysis: In this study, we focus on Feldspathic Highland Terrane (Anorthostic) (FHT, An) [6], a region characterized by a low concentration of FeO, ~4.2 wt % except for Mare Moscoviense. In particular, we use make the assumption that the porosity of the FHT, An region is constant and that trends observed in the derived porosity result from errors in the derivation of porosity from errors in the employed grain density. The crustal porosity data used here [3] is derived by inverting spherical harmonic degree and order $l = 150 - 310$ gravity data, which senses a deeper crust than the higher degree and order. We examine the derived bulk density and grain density data and assume that the derived porosity is primarily determined from the observed bulk density [2,4,8]. The bulk density variation in the lunar crust is mainly controlled by the amount of fractures generated by impact basins in the crust [7,8]. We also assume that the amount of porosity in the crust generated by basins is independent of the grain density of the pre-impact target. We compare the observed porosity and grain density for the FHT, An region, and find that a positive correlation between the observed LP-GRS grain density and the observed porosity (Figure 2). From the relationship between porosity (ϕ) and grain density (ρ_g),

$$\phi = 1 - \rho_b/\rho_g$$

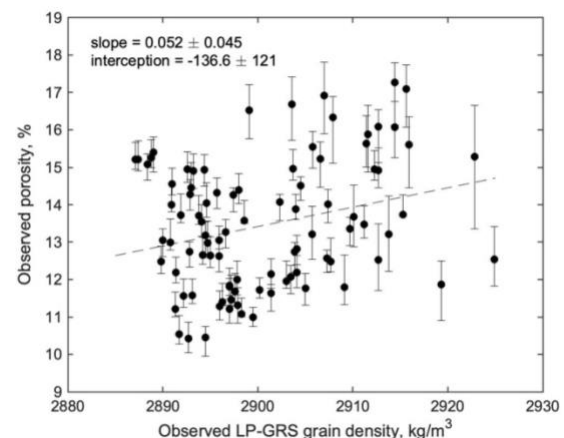, where ρ_b is bulk density, the higher grain density results in a greater porosity.

Figure 2: The relationship between the observed LP-GRS grain density and the observed porosity for FHT, An region.

Method: As the FHT, An region is surrounded by Procellarum KREEP Terrane, the contamination of

mare material in the lunar highlands is mainly from post-mare impacts [9]. To the first order approximation, the amount of non-highland material in this region can be modeled as a diffusion process [10]. We analyze the 1D diffusion equation and assume that the source of high grain density materials that cause a slightly upward trend in the relationship between the observed porosity and LP-GRS-derived surface grain density is homogeneous (constant diffusion process), so only the source from the mare–highland boundary would affect the surface composition. We select highland regions in the northwestern PKT, and derive a profile of the observed grain density as a function of distance from the nearest northwestern PKT mare–highland boundary (Figure 3).

Results: We impose an initial condition for the 1D diffusion analytical solution where the concentration at the mare–highland contact is 0.5 (50% PKT materials and 50% highland materials) and zero at infinity. Considering a total diffusion time of 3 Gyr from the initial emplacement of mare basalts, the diffusion constant parameter controls the total amount of mare material currently in the highlands region. Constraining this diffusion process from different types of source material in the PKT using a 2D diffusion equation or employing a more sophisticated model such as the Cratered Terrain Evolution Model (CTEM) [5,11,12] will be considered. Nevertheless, regions away from the boundary (e.g., ~1000 km) depict ~10% material from PKT if 500 km is taken at the face value for the diffusion length, which is similar to the observed grain density profile. This estimate is close to previous estimates [13,14].

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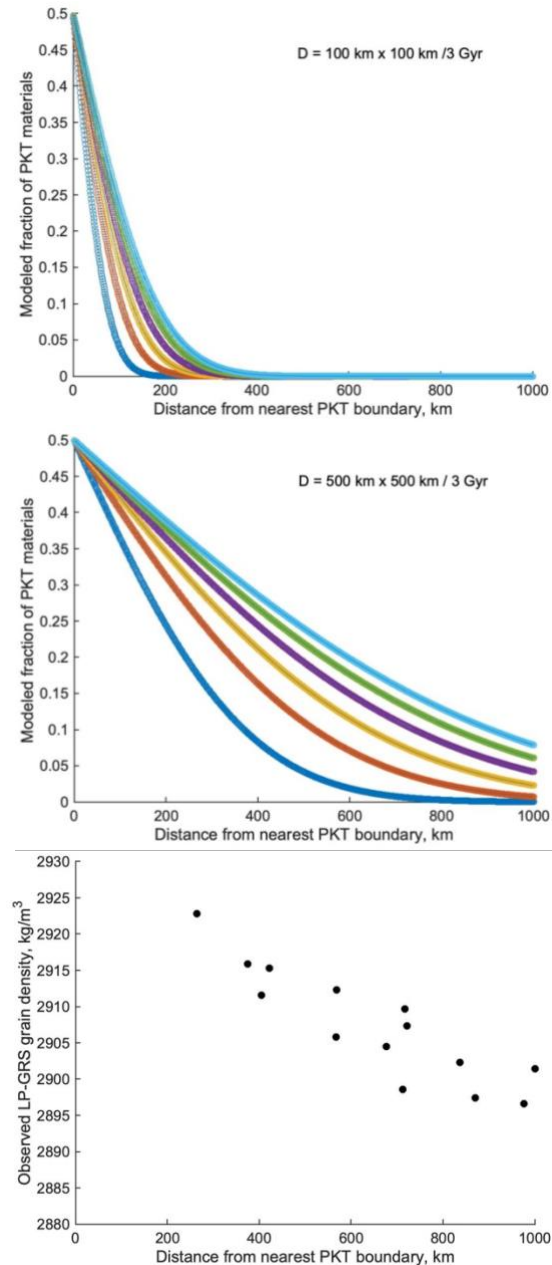

Figure 3: Modeled and observed diffusion profiles across Northwestern PKT boundary. The top and middle panels represent the results from analytical solutions for 1D diffusion equation with diffusion constants: 100 km × 100 km / 3 Gyr and 500 km × 500 km / 3 Gyr. The bottom panel is the observed LP-GRS grain density profile across the PKT–highlands boundary, as a function of distance from the nearest PKT boundary. The color lines represent diffusion profiles with different time from 0 to 3 Gyrs with the step of 0.5 Gyr.