LUNAR GLOBAL ALUMINUM MAP: RESULTS FROM CHANG'E-2 GAMMA RAY SPECTROMETER.

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Introduction: Geochemically, aluminum(Al) abundance and global distribution across the surface are crucial to decipher the origin and geologic evolution of lunar crust[1]. Lack of protective atmosphere and magnetic field makes the gamma ray remote sensing spectroscopy powerful for the determination of lunar chemistries (Fe, Al, Ca, Ti, Si, Mg, O, etc.) under the activation of neutrons released from cosmic ray bombardments[2]. Chang'e-2 gamma ray spectrometer (CE2GRS) has acquired lunar gamma ray spectra (Figure 1) with diagnostic gamma rays to derive Al concentrations of the Moon.

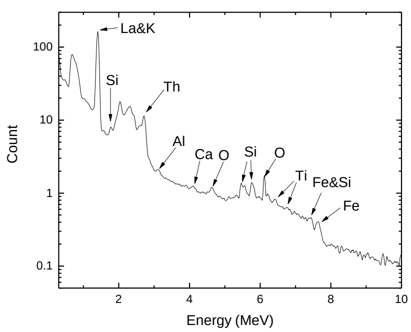

Figure 1 Lunar gamma ray spectrum measured by CE2GRS, peak identifications refer to [3]

Method:

Data preparation. CE2GRS level 2C data are distributed by the Ground Research and Application System of Chinese Lunar Exploration Program, and have undergone a series of preprocessing pipelines including gain correction, dead time correction, geometric correction, and orbit altitude normalization, etc. Besides, time-varying galactic cosmic rays(GCR) that initiate radioisotopes need to be measured and normalized. Inelastic scattering peaks of oxygen are ideal GCR sensors due to the uniform distribution of oxygen[4]. Benefited from the excellent spectral resolution of CE2GRS[5], O@4.438MeV peak could be identified upon less complicated background than O@6.129MeV peak previously popular in GCR corrections.

After eliminating of unavailable spectra (e.g., anomalously high values) within level 2C datasets, GCR variability is corrected for valid data prior to spectral accumulation, during which time series orbital data are mapped into quasi equal area pixels and lose the time properties.

Al Counting rate. As shown in Figure 1, Al@3.004MeV peak located exactly outside of the naturally radioactive region, away from complex spectral mixing. Compton continuum extended from high energy edge (i.e., 3.09~3.307MeV) could be estimated as straight line and removed to distinguish the composite peak of Al and Th (2.615MeV) from the background. We carry out local spectral fitting with multiple Gaussian functions, extracting the counting rate of Al peak.

Al@3.004MeV line originated from fast-neutron inelastic scattering reaction, $^{27}Al(n, n'\gamma)$, whose flux records the variations of Al contents as well as the fast neutron reserves in lunar regolith. Maurice et al. (2000) suggested the fast neutron flux is proportional to the average atomic mass(AM) of lunar materials[6], which have been reported by Lunar Prospector neutron spectrometer(LPNS)[7]. CE2GRS Al counting rates are scaled by the LPNS AM map consequently.

Calibration. We calibrate Al counting rate to the absolute abundance in terms of ground truths from lunar samples[8], meteorites[9] and *in-situ* detections (Table 1, Figure 2). It has long been known that the chemistry of soil and regolith breccias (returned by Apollo(A) and Luna(L) missions) are regarded as compositional representatives of extensive ejecta blanket area corresponding to remote sensing[10], yet sampled inside or adjacent to mare regions at the nearside, thus feldspathic meteorites(FLM) would be suitable supplements as highlands ground truth. In addition, our calibration model also accounts for the new type of basalt recently discovered by Chang'e-3(CE3) Yutu rover[11].

Results and Discussions: Global Al_2O_3 map (Figure 3) reveals diverse surface of the Moon: significant maria-highlands dichotomy; heterogeneity among mare units or highlands. On the nearside, mare could be separated from highlands with the contour line of 16 wt.% Al_2O_3, while the threshold value rises to 21 wt.% on the farside. In the perspective of lunar mineralogy and petrology, majority of Al ended up in the feldspar mineral group that dominates the feldspathic highlands terrane, by contrast, mare basalts are rich in Al-free and Fe-bearing/mafic minerals. A long-standing geochemical trend concerns the inverse correlation between Al and Fe, which was found in samples[8] and proved by remote sensing of Lunar Prospector gamma ray spectrometer(LPGRS)[12]. We have examined Al data derived from CE2GRS versus LPGRS Fe data (Figure 4), confirming the anti-correlation aforementioned and validating the accuracy of our Al map.

Table 1 Al_2O_3 contents of lunar soil and regolith samples, FLM and Chang'e-3 basalt and Al peak counting rate of CE2GRS utilized in calibration

Sampling Site	CE2GRS Al counting rate	Sample Al_2O_3 content (wt. %)
Apollo 11	31.02	12.58
Apollo 12	27.84	12.13
Apollo 15	42.38	14.32
Apollo 16	50.4	27.23
Apollo 17	40.58	18.93
Luna 16	25.56	15.68
Luna 20	47.22	22.75
FLM	48.96	28.2
Chang'e-3	23.64	9.7

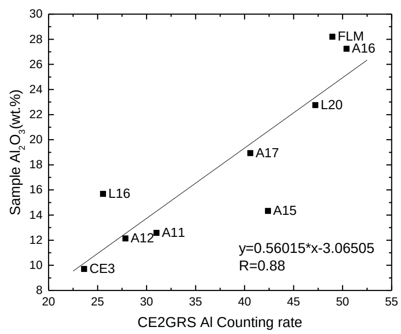

Figure 2 Scatter plots of Al_2O_3 contents in Apollo (A) & Luna (L) soil and regolith samples, feldspathic lunar meteorites (FLM) and Chang'e-3(CE3) detections versus CE2GRS counting rates. Result of linear fitting is shown as regression line, expression and correlation coefficient

Among contiguous mare/highlands units, there are also variations in Al_2O_3 ranging from 3 wt.% to 20 wt.% for mare, 19 wt.% to 31 wt.% for highlands, respectively. Different chemical features in mare regions generally corresponds to different geologic units from diverse sources at various evolution stage of the Moon. Correlating lunar chemistry (e.g. Al, Fe, Ti, etc.) with age is expected to shed light on lunar volcanic evolution over time. Highlands were continuously reshaped by impact excavations and ejecta deposits since its solidification from lunar magma ocean, resulting complex topography, mixing composition, etc. The compositional diversities of lunar highlands still requires further investigations with more and more returned lunar datasets.

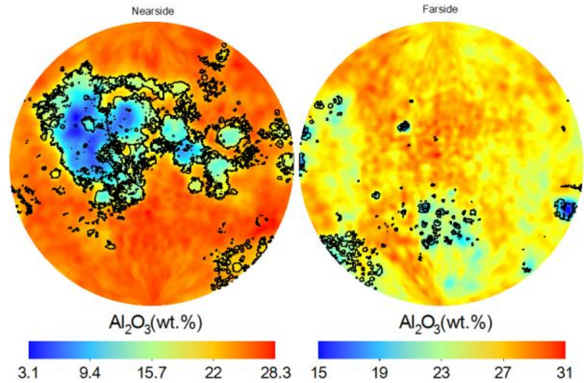

Figure 3 Lunar Al_2O_3 map derived from CE2GRS. Map is smoothed in a circle neighborhood with a diameter of 150 km. Mare region are outlined in black lines

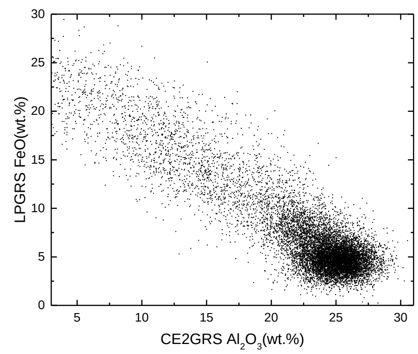

Figure 4 Scatter plots of CE2GRS Al_2O_3 versus LPGRS FeO

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