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Possible mantle origin of olivine around lunar impact basins detected by SELENE

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The composition, structure and evolution of the Moon's mantle is poorly constrained. The mineral olivine, one of the main constituents of Earth's mantle, has been identified by Earth-based telescopic observations at two craters on the near side of the Moon, Aristarchus and Copernicus[1-3]. Global reflectance spectra in five discrete spectral bands produced by the spacecraft Clementine[4-6] suggested several possible olivine-bearing sites, but one of the candidate occurrences of olivine was later re-classified, on the basis of continuous reflectance spectra over the entire 1 μm band, as a mixture of plagioclase and pyroxene[7]. Here we present a global survey of the lunar surface using the Spectral Profiler onboard the lunar explorer SELENE/Kaguya[7,8]. We found many exposures of olivine on the Moon, located in concentric regions around the South Pole-Aitken, Imbrium and Moscoviense impact basins where the crust is relatively thin. We propose that these exposures of olivine can be attributed either to an excavation of the lunar mantle at the time of the impacts that formed the basins[3], or to magnesium-rich pluton in the Moon's lower crust. On the basis of radiative transfer modelling[4,8-10], we suggest that at least some of the olivine detected near impact basins originates from upper mantle of the Moon.

The lunar magma ocean (LMO) scenario proposes fractional crystallization of LMO-produced mafic cumulates that made up the mantle, and plagioclase floatation that made up the crust[11,12]. Several models have been proposed that describe the compositional and structural evolution of a crystallizing magma ocean, but there are still uncertainties in the composition and structure. One of the reasons for the uncertainties is the lack of information on olivine exposure on the Moon, a plausible main material for the lunar mantle. Earth-based telescopic observations have reported only two nearside craters, Copernicus and Aristarchus, having olivine-rich spectral features[1–3]. Although Earth-based observations produce continuous reflectance spectra, the observational points are sparse and limited to the lunar nearside. On the other hand, the UVVIS camera onboard the Clementine spacecraft (hereafter Clementine), which had five discrete bands, provided global data of the Moon[4–6]. Olivine Hill in the South Pole-Aitken (SPA) basin and the central peaks of five craters were identified as possible olivine-bearing sites by Clementine[5,6]. However, after a re-examination using data taken by the Spectral Profiler (SP) onboard the Japanese explorer Kaguya, one of the Clementine candidates, the Tsiolkovsky crater, was classified as a mixture of plagioclase and pyroxene, rather than as pure olivine[7]. This SP finding demonstrated the importance of obtaining continuous reflectance spectra over the visible and near-infrared range covering the entire 1 μm band, which can be used to as a diagnostic tool for olivine and other silicates in identifying olivine exposure sites on the Moon.

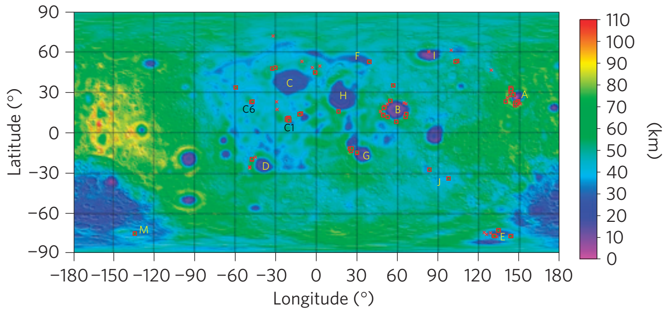

Figure 1 | Global distribution of olivine-rich points on the Moon. The background map is the total lunar crustal thickness (crustal materials and mare basalt fills) based on SELENE gravity and a topographic model produced by the Kaguya explorer[13,28–30]. The red squares indicate olivine-rich points with multiple SP data points showing a clear olivine spectral signature. The small red crosses indicate single SP detections. Note that most of the olivine-rich points are distributed around impact basins. The SP successfully detected olivine at the Copernicus (C1) and Aristarchus (C6) craters, which were identified as olivine-bearing areas by Earth-based observation[1–3].

The SP has obtained continuous spectral reflectance data for about seventy million points (a 0.2–0.5 km by 0.5 km footprint) on the Moon over the 0.5–2.6 μm wavelength range (λ) with a spectral resolution of 6–8 nm during its mission period from November 2007 to June 2009 (refs 7,8). Analysing all of the spectral data, we identified 245 olivine-rich points by picking up spectra having absorption band minima within the wavelength range of $\lambda = 1.05 \pm 0.03$ μm after removing a linear tangential continuum. Most of the spectra for the selected points (hereafter referred to as olivine-rich points) show clear olivine bands with $\lambda = 0.85$, 1.05 and 1.25 μm as shown in Supplementary Figs S1–S3, although some of the spectra show less clear olivine bands, which may be due to the presence of minor amounts of high-Ca pyroxene or other geologic units in the SP field of view.

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