Water detection using lunar mineralogical spectrometer onboard the Chang'E-5 lander. H. Lin[1], S. Li[2], R. Xu[3], Y. Liu[4], Y. Lin[1], Z. He[3] and Y. Wei[1], [1]Key Laboratory of Earth and Planetary Physics, Institute of Geology and Geophysics, Chinese Academy of Sciences, [2]Hawaii Institute of Geophysics and Planetology, University of Hawaiʻi at Mānoa, [3]Key Laboratory of Space Active Opto-Electronics Technology, Shanghai Institute of Technical Physics, Chinese Academy of Sciences, [4]State Key Laboratory of Space Weather, National Space Science Center, Chinese Academy of Sciences. (linhonglei@mail.iggcas.ac.cn).

Introduction: Understanding the water concentrations and distributions on the Moon is critical to constraining its formation and evolution, and to providing water resources for long-term human activities. Many orbital observations and sample measurements over the past decade have presented evidence for the presence of water (as hydroxyl and/or H_2O) on the Moon [1-3]. However, no in-situ measurements have ever been conducted on the lunar surface. The Chang'E-5 spacecraft landed in the Northern Oceanus Procellarum basin (43.06°N, 51.92°W) on the Moon on 1 December 2020 and successfully returned 1.731-kg samples on 17 December 2020 (Fig. 1a). The mare basalt at the landing site is very young (~2.0 billion years), younger than all the known lunar basalts [4, 5]. Before sampling and returning the lunar soil to Earth, the lunar mineralogical spectrometer (LMS) onboard the lander performed spectral measurements of the regolith and a rock, providing the unprecedented opportunity to detect lunar surface water.

Data and methods: LMS onboard the Chang'E-5 lander can measure the reflectance spectra of the lunar surface from 0.48 to 3.2 μm with a spectral interval of 5 nm. Reflectance spectra of the regolith and a rock (named as "CE5-Rock" hereafter) around the sampling site (Fig. 1b) were acquired by the LMS. The LMS spectra are significantly affected by the thermal emission from the lunar surface. Thus, we followed an empirical model developed by Li and Milliken [6], which has been successfully applied to Moon Mineralogy Mapper spectra of Chandrayaan-1 mission and validated using Chang'E-4 spectra [7], to remove the thermal effects from the measured LMS spectra. A Hapke's model was then used to perform the photometric correction for all LMS data.

The absorption features at ~3μm were analyzed to characterize the water content at the sampling site. The effective single-particle absorption thickness (ESPAT) at ~3μm was used to derive water content in the lunar regolith. So we estimated the water content from the ESPAT parameter using the same method in [3]. Hapke spectral unmixing model [8] was used to estimate the mineral compositions at the sampling site from the LMS spectra.

Results: The spectrum of CE5-Rock exhibits a strong absorption at 2.85 μm because of the presence of OH/H_2O. By contrast, most of the lunar regolith at the landing site exhibit no/weak absorptions at 2.85 μm. The 2.85 μm absorption band in the rock spectrum is about twice stronger than that in the regolith spectra, indicating potentially higher water content in the rock. The quantitative analysis indicates that the lunar regolith at the landing site contains less than 120 ppm water, mostly attributed to solar wind implantation. This is consistent with the preliminary analysis of the returned Chang'E-5 samples. In contrast, CE5-Rock exhibits a much stronger absorption at 2.85 μm with estimation of about 180 ppm water [9]. The excess water signature in CE5-Rock may suggest extra sources of water in addition to solar wind implantation.

Discussion: The laboratory studies on hydrous minerals revealed that the absolute water contents can be linearly correlated with the ESPAT values at 2.85 μm, but the linear coefficient varies with the particle size of lunar analogs [3]. It should be noted that the grain size of CE5-Rock is difficult to be determined. The reflectance near 3 μm of CE5-Rock is mostly from the top 1-mm layer (the optical depth of light near 3 μm), because most of the light that propagates beyond the optical depth (approximately in millimeters) cannot be reflected to the sensor. In this case, the derived water content is around 70 ppm, which is similar to that observed in the surrounding regolith. Alternatively, the top surface of CE5-Rock may have been space-weathered to fine particles (e.g., 60 to 80 μm), and the derived water content is around 180 ppm. Our modeling results suggest that the surface of CE5-Rock is fine-grained in texture, which is also commonly found in rapidly cooled mare basalts of Apollo samples. If that is the case, then our estimation of water content at around 180 ppm based on an effective particle size of 60 to 80 μm is reasonable, which is at least 60 ppm higher than that of the surrounding regolith (Fig. 1). The value of 60 ppm is notably higher than our model uncertainty of 36 ppm (20% of 180 ppm).

Compositional and orbital remote sensing analyses suggest that CE5-Rock may be excavated from an older low-Ti basaltic unit and ejected to the landing site of Chang'E-5 [9, 10]. This older low-Ti mare basalt unit also exhibits anomalously high water content that was attributed to a source from the lunar interior [11]. By comparing with the regolith, the "excess" water detected in the CE5-Rock may originate from additional sources, such as remnant water within a rock derived originally from the lunar interior.

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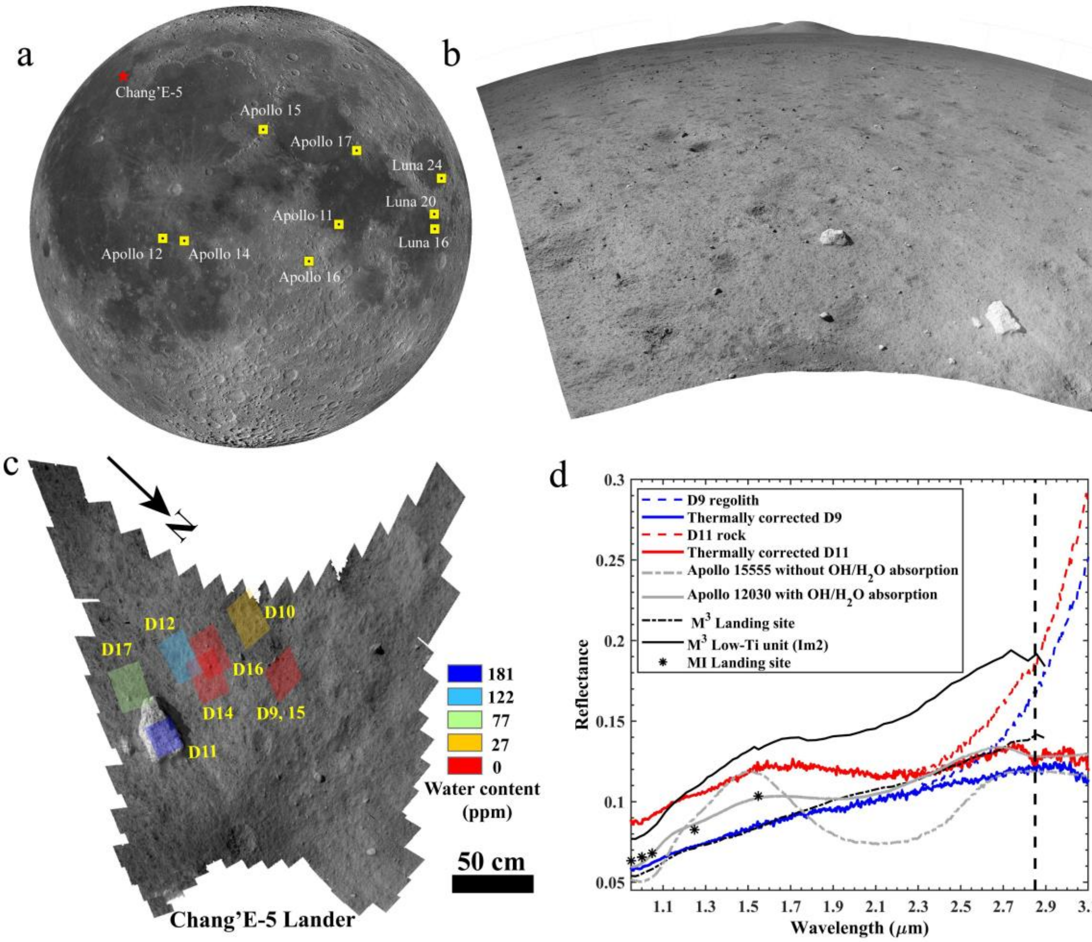

Fig. 1. In-situ exploration of the Chang'E-5 lander on the lunar surface. (a) The locations of all lunar sample return sites. (b) The image of the sampling site acquired by the panoramic camera onboard the Chang'E-5 lander. (c) The derived water content at the sampling site of Chang'E-5 [9]. (d) Examples of thermally and photometrically corrected Chang'E-5 LMS reflectance spectra. [9].