AN EXPLANATION OF BRIGHT AREAS INSIDE SHACKLETON CRATER AT LUNAR SOUTH POLE OTHER THAN WATER ICE DEPOSITS:

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Introduction: Whether water-ice deposits exist in the permanently shadowed areas (PSAs) of lunar polar regions is heavily debated among scientists. We previously reported the albedo of the floor of the lunar south-pole Shackleton crater (SC) [1] (Fig. 1a) where the existence of water-ice had been indicated by the Clementine bi-static radar experiment [2, 3] and by high hydrogen concentrations based on Lunar Prospector Neutron Spectrometer observation [4]. The inside of the crater was momentarily illuminated by scattered light from the upper inner walls of the crater. The Terrain Camera (TC) on the Selenological Engineering Explorer (SELENE, nicknamed Kaguya) acquired images of the inside of SC at that moment. From the images, we concluded that there is very little or no water-ice on the floor surface of the crater. The result was consistent with Earth-based radar observations [5] that had indicated little evidence of water-ice deposits, although the observations were limited to the upper part of the inner wall of SC.

Later, the far ultra violet reflection observation by the Lyman Alpha Mapping Project (LAMP) on the Lunar Reconnaissance Orbiter (LRO) presented similar results: The inside surface of SC may be covered by water-ice frost but the amount is at most a few percent [6]. The floor surface of PSAs like inside SC may be desiccated because water molecules would migrate into the subsurface. Even so, the migration process would lead to a much smaller amount of H_2O in the subsurface layer, depending on the grain size, probably up to a few hundred ppm in excess of what is chemisorbed and extremely strongly adsorbed [7].

Recently, Zuber et al. (2012) [8] analyzed the 1000 nm beam reflection data of LRO LOLA for SC and provided much suggestive information for the storage of water-ice inside the crater. Their research suggested that the rollover in the curve at hundreds meter scale small crater diameters of the floor of SC is very similar to that seen outside SC. It is thus more likely to be due to the typical destruction effects of superposed craters. It therefore cannot be concluded that volatiles exist on the surface or subsurface regions, though diffusion may transport the volatiles much deeper underground as the small crater distributions are not affected.

In contrast, the authors reported the reflectance of both SC floors and walls for LOLA beams to be as much as 50%, considerably higher than that of the surrounding terrain. They stated that the high reflectance of SC's inner surfaces could be explained by a dearth of space weathering by micrometeorite bombardment, but they also proposed possibly 20% water-ice deposits inside of SC to explain the high reflectance. The hypothetically asserted amount of water-ice inside SC would be highly desirable for those who strongly hope for future human activities beyond low-earth orbits. However, such amounts of the water-ice on the surface of SC are seriously inconsistent with the results from previous studies.

Yamamoto et al. (2012 [9] reported the existence of the purest anorthosites (PAN) on SC's upper inner walls based on the data of the SELENE Spectral Profiler (SP). SP first identified clear absorption at 1250 nm, indicating the existence of PAN at several locations on the Moon (e.g., the central peak of Tsiolkovsky crater [10]. Subsequently, the wide distribution of PAN over the lunar surfaces was confirmed based on the SELENE Multi-band Imager (MI) [11] and then Yamamoto et al. (2012) [9] performed a global survey of PAN by SP.

PAN has very high reflectance [e.g. 12]. The high reflectance of the SC inside surfaces in the SP data could be explained by this very bright material. However, SP is a line profiler with a footprint of 500 m [10, 13], although it could provide continuous spectra giving clear evidence of the PAN's 1250 nm absorption. Thus,we studied the distribution of PAN over the SC walls, based on the MI data. The MI data provide the areal distribution information of PAN with higher spatial resolution.

Purest Anorthosite at Shackleton Crater walls: The SELENE MI is a multi-spectral imager with four or five color bands with 20m or 62m pixel resolution from SELENE's nominal altitude of 100 km. MI was installed on SELENE to provide data distinguishing the geological units in detail [13]. The band assignments of MI are 415, 750, 900, 950, and 1000 nm in the visible range and 1000, 1050, 1250, and 1550 nm in the near-infrared ranges. MI successfully provided global coverage of the Moon.

Shackleton Crater is 19 km in diameter and is located in the lunar south polar region. The south pole is located on its crater rim (Fig. 1a). The inclination of the lunar rotation axis is 5 degrees [1]. The angle is small, but the polar regions have a summer (more illuminated) and a winter (more shadowed) in a year. The SELNE mission period was about one and a half years from December 2007 (the summer of the lunar south pole) to June 2009 (the winter there). MI had opportunities to acquire images of the lunar south polar region covering the SC. However, there were considerable possibilities for MI to miss imaging the SC. SELENE was controlled to maintain its orbital inclination within a few degrees. The angles were small. However, the MI swath was 19 km, narrower than the distance of the shift from 90° to lower latitudes due to the SELENE orbital inclination. In addition, the data transmission rate from SELENE to the Earth and the onboard data-storage capacity were too limited for MI to acquire SC images every orbit. Luckily for us, however, MI imaged the SC several times during the south-pole summer.

The Shackleton crater rim is inclined a few degrees. The rim at higher latitudes is more elevated than at lower latitudes. The upper inner wall, about 20% at maximum, is illuminated on the higher rim side. We found that MI acquired images of the SC upper walls several times during the SELENE mission. In contrast, the inner wall of the opposite rim side was not so illuminated even in the south-pole summer. The illuminated walls imaged by MI are like very thin crescents.

Figure 1b presents MI 1000 nm band data of SC's upper inner wall of the higher rim at higher latitude. The reflectance of most of that portion exceeds 30% at normalized conditions of 30°, 0°, and 30° for incidence, emission, and phase angles, consistent with the LOLA observation. Figure 1c presents an MI ratio image for reflectances of 1050 nm to 1250 nm of the same region as in Fig. 1b. The higher ratio indicates deeper absorption at 1250 nm, implying the existence of PAN. The brightest points (50% reflectance) in 100 nm in Fig. 1b correspond to the red in Fig. 1c where the ratio is high with deep absorption at 1250 nm and are rich in PAN.

The data acquired by SP and MI inside SC are limited because of the short summer, inclined SC rims, and SELENE orbital shifts. However, there may be numerous outcrops of PAN rock on the inner wall of SC at the higher side which would highly reflect LOLA beams.

Plagioclase, the major material of lunar highlands, is very bright. Its reflectance measured in laboratories was up to 60% [12]. Inner walls are fresh with higher reflectance than normal surfaces. SC has uniquely steep slopes of the inner walls (about 30°) [1,5,8] that could have caused continual landslides exposing fresh surfaces. Immature material at lunar higher latitudes was also confirmed by Yokota et al. (2011) [13] based on SP data. In conclusion, the brighter inside of SC could be explained by the distribution of very bright, fresh plagioclase, probably PAN, rather than by water-ice frost of more than 20%, which may be highly desirable but is implausible.

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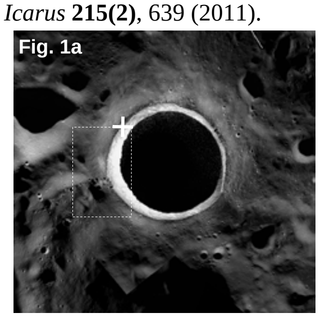

Fig.1a: A mosaic image of Shackleton Crater (SC) of nearly 20 km diameter at the lunar south pole from the panchromatic data of Terrain Camera aboard SELENE (Kaguya). The white cross indicates the lunar south pole.

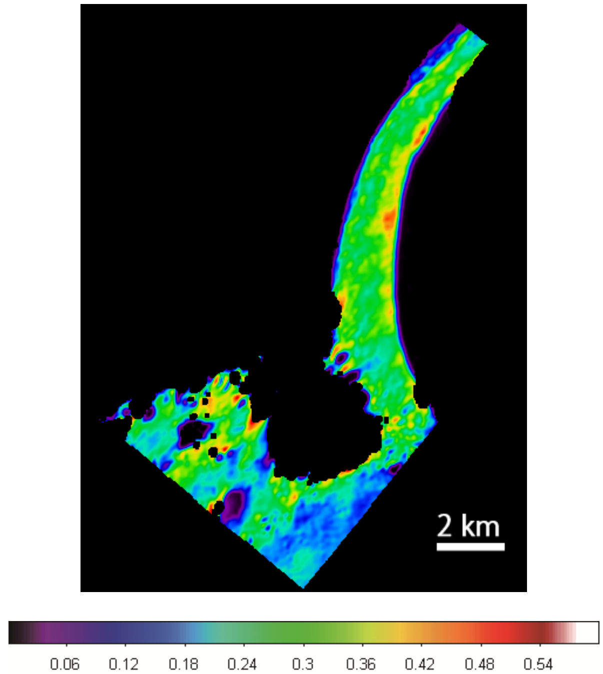

Fig. 1b: A Multiband Imager (MI) 1000nm band image of a part of SC indicated by the white dashed box of Fig. 1a.

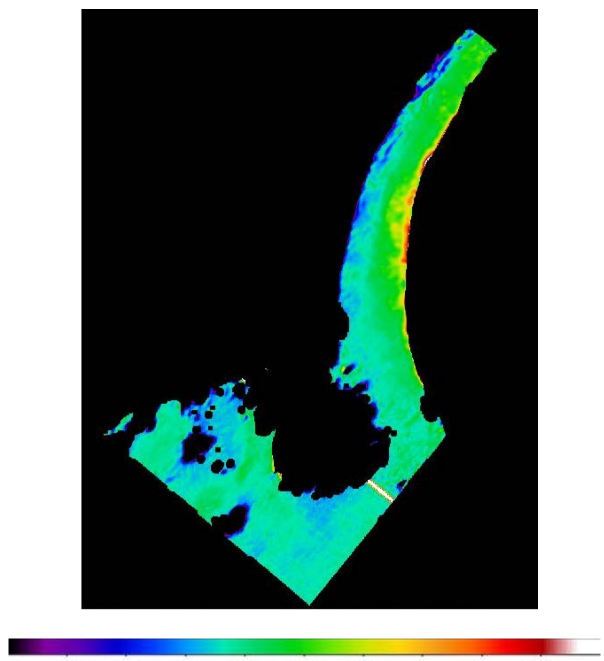

Fig. 1c: A MI ratio image for reflectances of 1050 nm to 1250 nm of the same region as in Fig. 1b. The higher ratio (yellow to red) nearly corresponds to the deeper absorption at 1250 nm, indicating the existence of PAN. At the portion of white, the ratio of 1050 nm to 1250 nm could not be computed because of missing 1050 nm data.