WATER ICE ON THE MOON

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Summary: To construct basement on the Moon in future, the places are favorable where water resources and power energy supporting for human being provided. Both of lunar poles are exactly what we are searching for. Scientific researches and detection of the lunar water ice through multidiscipline integration achieved by historical and recent missions are necessary to reviewed in methodology here to figure out the direction to future planetary sciences and explorations. It is concluded that the water in many kinds of formation like water ice with a few meters thick buried by a thin (a few cm) regolith is deposited at cold traps in permanently shadowed region at lunar poles. The water ice originated by solar wind, comets impacts or other unknown reasons.

Introducion: Early history of lunar explorations, lunar samples returned in Apollo missions revealed that volatile elements were depleted on the Moon. Permanently shadowed areas were the first detected by the data from the camera onboard Clementine, and the possibility of deposits of water ice in those regions was supported by measurements from Bistatic Radar Experiments in the same spacecraft[1]. Although Lunar Prospector approved that the method to detect hydrogen in lunar regolith of epithermal neutrons flux was 10 times more effective than that of fast neutrons flux, the possibility of water ice had not been confirmative since then, mainly for ambiguous areas of permanently shadowed regions (PSRs)[2]. Therefore, topographic data in high accurate and solar illumination condition at poles in future missions are needed to precisely qualified the areas of PSRs at lunar poles. The possibility of water ice in subsurface at poles is needed to be confirmed with further information of epithermal neutrons flux and other types of remote sensing.

Many instruments and approaches in recent missions and multidiscipline researches support exist of water ice deposited by upper drier regolith layer on surface and contribute to the relatively accurate quantification. In 2007, solar illumination conditions at eternal light and permanently shadowed regions were established by DEM and images by LALT and TC cameras in Kaguya mission. In the following two year, The measurements of hydroxyl/water-bearing materials at poles by M^3 detector and Mini-SAR in Chandrayaan-1 spacecraft provided clues for US LRO mission and probably explanations of the origin. The content of water ice at one of PSRs at lunar South Pole was estimated by detection of ejecta plume by spectrometers on LCROSS, of hydrogen by LEND and temperature by DIVINER.

Method A: Solar Illumination Conditions on Lunar Poles. Because of the tenuous atmosphere of the Moon, the temperature of its surface is susceptible directly to the sunlight condition. As the photographic data coverage from Clementine was limited to the summer in the northern hemisphere, the study in sunlight condition of lunar polar regions was blocked. DEM are alternative approach to estimate the sunlit condition. Until 2007, the completed coverage of topography was established from data from LALT on KAGUYA. The sunlit condition at the polar areas was calculated by using the DEM model and the DE403 ephemeris file for 2000 days. The results showed that no regions of eternal light at the polar but permanent night places in both regions. These locations were candidate landing sites for lunar exploration in the near future, in which in highest rate of illumination can provide energy and resources, and in permanent is possible condition for water ice deposits for future exploration.

The highest rate located at (88.1N, 117.6E) in the north is 89 percent of 2000 days and in the south highest rate of 86% is located at (88.8S, 124.1E)[3][4]. Shown in the Figure 1, the areas of permanently shadowed regions above the latitude of 85 degree are 1236 and 4466 km^2 for south and north poles respectively, and of 88 degree are 844 and 2751 km^2.

Method B: Detection of Hydroxyl and Hydrogen. M^3 onboard Chardrayaan-1 designed by NASA with 140m/pixel detected absorption features near 2.8-3.0 micrometers on lunar surface. For silicate planet, such feather is typically attributed to hydroxyl- and/or water-bearing materials. The feature of distributed OH/H_2O absorptions appeared increasingly stronger at cooler and higher latitude and several shadowed craters.

The measurements by M^3 identified the possibility of presence of hydroxyl- and/or water-bearing materials. The abundance could be 770ppm in lunar soil[5], not so much as predicted. The H detected by the Lunar Prospector Neutron Spectrometer (LP-NS) represents the upper 50 cm of the regolith, and the OH/H_2O by M^3 yielded from the upper few millimeters of the lunar soil. The non-correlation indicates the formation of OH/H_2O is originated in surficial process, most possibly solar wind[6].

The target called SP_C within the Cabeus crater was chosen from the nine candidates sites for the final impact according to the estimate of hydrogen on basis of the epithermal neutron flux measured by LEND[7]. Suppressed neutron flux in a region demonstrates the high concentration of hydrogen. PSRs by LOLA are not spatially coincident with neutron suppression region (NSR) by LEND.

The subsurface temperature in the NSR detected by LRO-DIVINER is 60K[8]. The estimate hydrogen content of SP_C within Cabeus crater is 470ppm and highest among the nine candidate impact sites. The corresponding value of 4% water ice by weight is coincident with the estimates of the water content of 5.6±2.9% by weight from detection of debris plume. The formation of the hydrogen is possibly the implantation of solar wind protons and comets impact or other unknown hypothesis.

Method C: Temperature. Before impact of LCROSS, surface bolometric brightness temperatures at summer solstice measured by Diviner with spatial resolution of 200m are 46.7K at daytime and 38.7K at nighttime in the region around the impact sites. And calculated annual average temperature of the target is about 38K[8], which is extremely cold enough to permanently trap volatiles including water ice.

Method D: Radar Reflection Responses of Water Ice Layers. Backscatter properties in some regions at lunar poles had been discovered by bistatic radar experiments[1], and circular polarization ratio(CPR) was calculated from the measurements. Elevated properties in CPR derived by bistatic radar of Clementine, Mini-SAR on Chandrayaan-1 and Mini-RF onboard LRO[9].

The fresh craters like Main L with elevated CPR in both interior and exterior to the rim are caused by surface roughness. Some craters in diameter of 5-15km in permanently shadow with high CPR only in interior of the craters probably represent deposits of water ice. Shown in Fig.4, more than 30 craters in North Polar Region with water ice were found. The water ice layer with about 2-3m thick was detected to be buried by upper layer of regolith with few centimeters[9].

Method E: Analysis of Content of Ejecta Plume by Impact. The final impact target by LCROSS changed from Cabeus A to the Cabeus crater (84.9S, 35.5W) of the diameter of 98km located about 100km away from south pole of the Moon. The decision was made according to the observations from Lunar Prospector (LP), Lunar Reconnaissance Orbiter (LRO), Chandrayaan-1 and Kaguya spacecraft. The recent results illustrate the highest concentration in Cabeus cater with greatest level of certainty, and higher precisely detection with excellent, high-contract back drop for ejecta plume measurements[10].

The detection of water vapor by near-infrared spectrometers and hydroxyl materials by ultraviolet/visible in the ejecta plume confirmed the presence of water in lunar regolith. The temperature in the target crate is less than 50K, making a cold trap to collecting and preserving volatiles over billions of the years. Total water vapor and water ice measured was 155±12 kilograms, and the concentration by mass of water ice in the regolith was evaluated to 5.6±2.9% in 2175±544 kilograms of total dust mass[11]. Besides water, the abundance of other volatiles species in the debris plume was determined, including H_2S, NH_3, SO_2, C_2H_4, CO_2, CH_3OH, CH_4, OH[8,11].

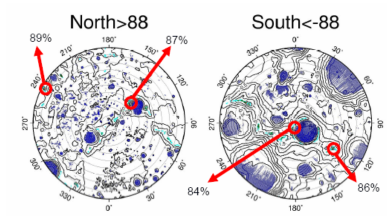

Fig. 1 *Results of illuminated rate in lunar poles* [4]

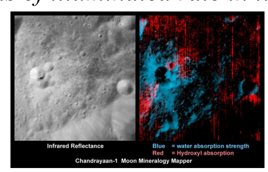

Fig. 2 *The strength of absorption of OH(Red)/H_2O(Blue) in a very young lunar crater*[5]

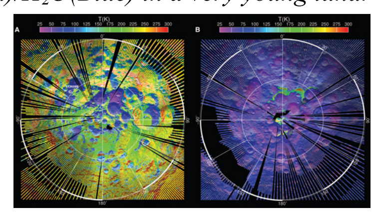

Fig.3 *Diviner-measured bolometric brightness temperature at daytime (left) and at nighttime* [8]

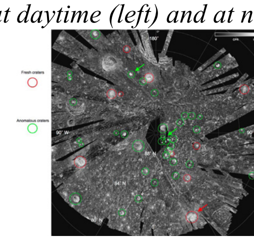

Fig.4 *CPR map of the north polar region of the Moon. Red circles present the high CPR caused by surface roughness and green ones present the high CPR with water ice deposits*[9]

References: [1] S. Nozette etc. (1996) *Science* [2] W. C. Feldman etc.(1998) *Science* [3] H. Noda etc.(2008) *GRL* [4] H. Araki etc.(2009) *Kaguya official website* [5] NASA Instru. Reveal Water Molecules on Lunar Surface [6] C. M. Pieters etc.(2009), *Science* [7] I. G. Mitrofanov etc.(2010) *Science* [8] David A. Paige etc.(2010), *Science* [9] P. D. Spudis, etc.(2010), *GRL* [10] NASA's LCROSS Mission Changes Impact Crater [11] Anthony C. etc.(2010), *Science*