ANALYSIS OF CPR CHARACTERISTICS FOR ANOMALOUS CRATERS AND IMPLICATIONS FOR LUNAR ICE DETECTION. Wenzhe Fa and Yuzhen Cai, Institute of Remote Sensing and Geographical Information System, Peking University, No. 5 Yiheyuan Road, Beijing100871, China (wzfa@pku.edu.cn).

Introduction: Detection of potential ice deposits at permanently shadowed areas near the poles of the Moon using radar signatures has been remained as a challenging task for nearly 20 years [1, 2]. Since 2008, two orbital miniature synthetic aperture radars (Mini-SAR and Mini-RF) on Chandrayaan-1 and Lunar Reconnaissance Orbiter (LRO) missions, have imaged the lunar surface with the main purpose of detecting the polarimetric signature of ice at the lunar poles [3]. Spudis et al. [4] analyzed initial radar data for the north pole of the Moon that acquired by Mini-SAR, and found that some craters show elevated circular polarization ratio (CPR) in their interiors, but not exterior to their rims. Almost all these anomalous craters are in permanent sun shadowed regions, and their CPR characteristics are different from those of fresh craters. Based on the correlation with Lunar Prospector neutron data and thermal conditions, these anomalous craters were interpreted as sites for water ice deposits [4]. However, this conclusion was based on statistical properties of CPR, and physical mechanisms for the enhanced CPR were not analyzed.

In this study, CPR characteristics for anomalous craters in polar and equatorial regions were studied using LRO Mini-RF data. The influences on CPR by radar incidence angle, surface slope, dielectric constant and rock abundance were analyzed systematically. We found that there is no apparent difference in CPR statistical characteristics between anomalous craters that located in polar and equatorial regions. In fact, the elevated CPR for anomalous craters is most probably caused by double scattering from surface rocks.

CPR Characteristics for Anomalous Craters: CPR is defined as the ratio of the received power in the same sense of circular polarization as that transmitted to the received echo in the opposite sense of circular polarization as that transmitted. Both theoretical study and observations show that CPR is strongly modulated by radar frequency, incidence angle, surface slope and roughness, abundance and shape of rocks, and dielectric properties of regolith [5, 6].

To analyze potential factors that cause the enhanced CPR in crater interior, two anomalous bowl-shaped craters were selected in our analysis: Cardanus E (12.8°N, 70.8°W; 6 km diameter) and Rozhdestvenskiy N (84°N, 157.4°W; 9 km diameter). Cardanus E is a typical anomalous crater that is located in equatorial region. Figure 1a shows CPR image of this crater from Mini-RF observation, where radar illumination is from the left with a nominal incidence angle of 52.4°. The black and blue lines in Figure 1b show CPR histograms for its interior and exterior, and the red and green lines show CPR histograms for crater walls that tilt toward (right side) and away (left side) from radar, respectively. The mean CPR values for crater interior and exterior are 0.83 and 0.55, respectively. Figure 1c shows local incidence angle of radar wave that calculated based on Kaguya DTM data. As can be seen, local incidence angle for crater wall that tilt away from radar varies from 50° to 90°, and that for cater wall tilt toward radar varies from 10° to 50°, which creates highlights and lowlights in CPR image. Statistical results show that slope of crater wall can cause a change in CPR about 0.09 and 0.18.

Rozhdestvenskiy N is a bowl-shaped anomalous crater that is located in lunar north polar region, as previously noted by Spudis et al. [4]. Figure 1d shows CPR image, where radar illumination is from the right with an incidence angle of 51.7°. Figure 1e shows CPR histograms for this crater, with the same convention for the lines as in Figure 1b. The mean CPR for crater interior is larger than that of the exterior region, with a value of 0.36. Figure 1f shows local incidence angle of radar wave that calculated from Lunar Orbiter Laser Altimeter (LOLA) polar data. As can be seen, crater walls play a similar role in local incidence angle, with a variation range of roughly 30°. CPR for crater wall that tilt away from radar is about 1.03 and that of crater wall title toward is about 0.82, all of which are much larger than CPR of crater exterior region.

Analysis and Discussions: Table 1 shows statistical results of CPR for these two anomalous craters, including its mean value (μ), standard deviation (σ), skewness (γ_1) and kurtosis (γ_2). As can be seen, there is almost no apparent CPR difference for these two anomalous craters. Cardanus E is in equatorial regions, where ice deposits cannot exist within regolith given the thermal condition.

From Figure 1b, CPR difference between interior and exterior region of Cardanus E is 0.28. Using FeO and TiO_2 abundance that derived from Clementine Ultraviolet/Visible data, dielectric constant for interior of Cardanus E is estimated as 2.83+i0.018, and that of exterior region is about 2.85+i0.023 [7]. According to theoretical study as in [5], such small difference in dielectric constant cannot create a CPR difference as large as 0.28.

Analysis of LRO Narrow Angle Camera (NAC) images shows that there are plenty of rocks on the surface within the crater rim of Cardanus E, with size about several meters. In contrast, there is almost no surface rock for its exterior of crater rims. Rocks on lunar surface can form a dihedral structure, which can cause double scattering with a CPR as large as 5 that depends mainly on radar incidence angle and dielectric properties of rocks. Suppose CPR for a rock-free surface is 0.4 and CPR of double scattering is 4, a rock fraction of 0.1 (with size at Mini-RF wavelength scale) would result in a CPR value of 0.8 based on a two-component mixed model, which matches well with the observations.

Given the high latitude, most of Rozhdestvenskiy N is in permanent shadowed region, and only a very small region near its rim can receive sunlight. Careful examination of LROC images for the visible region shows that its surface is also occupied by rocks. Given CPR statistical characteristic of this crater is very similar to that of Cardanus E, it is probably that the enhanced CPR value for the interior of Rozhdestvenskiy N is mostly caused by surface rocks, instead of ice deposits as previously explained by Spudis et al. [4].

Conclusions: In this study, Mini-RF CPR characteristics for anomalous craters that located in lunar north pole and equatorial regions are studied. Our results imply the following: (1) For a typical bowl-shaped crater, slope of crater wall varies from about 25° to 35°. This can cause a change in local incidence angle about 30°, and a change in CPR about 0.2. (2) Statistical results show that there is almost no apparent difference in CPR characteristics for anomalous craters that located at polar and equatorial regions. (3) The elevated CPR for interior of anomalous craters cannot be caused by dielectric constant and surface slope of crater wall. In fact, the enhanced CPR is most probably caused by surface rocks, suggesting that ice deposits is not the only physical agent for the enhanced CPR.

Acknowledgements: This work was supported by the National Natural Science Foundation of China (No. 11203002).

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Table 1. CPR statistics of two anomalous craters.

	Rozhdestvenskiy N		Cardanus E	
	Interior	Exterior	Interior	Exterior
μ	0.93	0.57	0.83	0.55
σ	0.50	0.35	0.46	0.33
γ_1	1.83	2.63	2.19	2.11
γ_2	7.66	16.65	10.19	10.28

μ: mean value; σ: standard deviation; γ_1: skewness; γ_2: kurtosis.

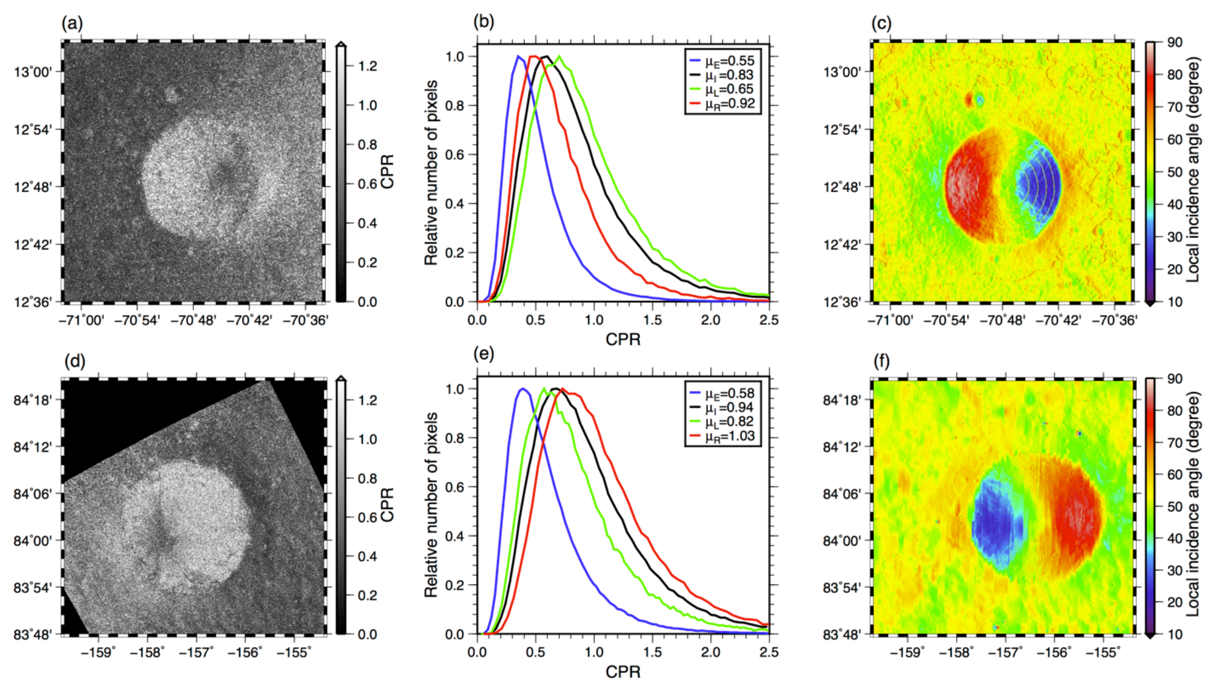

Figure 1. (a) CPR image for Cardanus E (12.8°N, 70.8°W; 6 km diameter), where radar illumination is from the left. (b) CPR histogram for Cardanus E. (c) Local incidence angle of radar wave for Cardanus E region. (d) CPR image for Rozhdestvenskiy N (84°N, 157.4°W; 9 km diameter), where radar illumination is from the right. (e) CPR histogram for Rozhdestvenskiy N. (f) Local incidence angle of radar wave for Rozhdestvenskiy N region.