MEASUREMENTS OF THE PERMITTIVITY, DENSITY, AND VOLUME FRACTION OF CRACK AROUND ARTIFICIAL IMPACT CRATER.

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Introduction: Many meteorites impact the lunar surface. The lunar terrain and geological condition (i.e., density and porosity) of the surface layer are affected by them. The porosity and bulk density of the lunar subsurface materials are expected to depend on their bulk permittivity based on the measurements of Apollo samples [e.g.,1], so lunar geological condition in the maria was investigated by estimating the bulk permittivity of uppermost basalt layer around impact crater based on radar observation (~5 MHz) [2]. For example, the bulk permittivity of uppermost basalt layer in Mare Humorum was ~2.8–5.5, which suggests that bulk density was ~1.6–2.6 and porosity was 19–51%.

For the estimation of porosity from bulk permittivity, the previous study [2] assumed a homogeneous and isotropic vesicle in subsurface layer. However, the impact-induced macro crack can produce an anisotropy of crack in subsurface layer, and an effective medium theory suggests that this anisotropy can change the bulk permittivity of subsurface layer even if the subsurface layer has the same porosity [e.g., 3]. In this study, we measured the relation among various physical parameters (i.e., bulk permittivity, bulk density, and volume fraction of crack) around artificial impact crater by performing an impact experiment.

Impact experiment and production process of measurement sample: We performed an impact experiment by using the two-stage light-gas (hydrogen) gun at JAXA on December 2014. Using the gun, we launched two spherical stainless projectiles (0.32 cm in diameter and 0.133 g in mass) at the velocities of 3.586 km/s (Case I) and 5.638 km/s (Case II), and produced an artificial impact crater on two basalt targets with size of 20 cm × 20 cm × 10 cm (Fig. 1a). The bulk density of the targets was ~2.931±0.003 g/cm^3, and these basalt targets included small vesicles, which seem to result from the degassing of volatiles and gaps among minerals.

Next, we drilled the impacted basalt targets, and produced core samples with a diameter of 2.5 cm, and a length of 8–10 cm along depth direction (i.e., perpendicular to the impacted surface) and horizontal direction (i.e., parallel to the impacted surface) (Fig. 1). Finally, we sliced the core sample into samples with a thickness of ~3–4 mm, and polished their surfaces in order to measure the bulk permittivity and crack distribution on the surface. The reason why we produced core samples in two directions (z and x directions in Fig. 1) is to investigate the dependence of the bulk permittivity on crack's anisotropy with respect to the impressed electric field used in the measurement. This investigation gives us the opportunity of the verification based on effective media approximation theory [e.g., 3].

Measurements of bulk density, bulk permittivity, and volume fraction of crack: The bulk density of sliced sample was derived from the ratio of measured mass and volume. The bulk permittivity and loss tangent were measured at a frequency of 5.0 MHz by using an impedance analyzer (TOYO Technica Corporation, Type-1260) with sample holder interface. The volume fraction of crack of sliced sample was measured by the following image processing, in which image processing software (Adobe System Incorporated, Photoshop) was used. First, we took a digital color image of the sliced sample’s surface by using a scanner. In order to emphasize crack on sliced sample, we performed a tone adjustment of digital image data. The crack on sliced sample became a whitish area because the fine fragments of crashed rock partially filled crack. We converted color image to grayscale image, and emphasized the cracks in the image by applying the contrast and brightness controls, which were adjusted to maximum values. After that, we converted the grayscale image to black and white image using a threshold of 40 in grayscale of 0 (white) – 255 (black). Through above processes, we could obtain the crack distribution on sliced sample.

Results and Discussion: In Fig. 2, we compared parameters in the core sample in depth (z) direction with those in horizontal (x) direction. Both in Cases I and II, the measured bulk density and bulk permittivity showed a clear inverse correction with the volume fraction of crack. The parameters estimated in the core sample in both directions roughly overlapped. In Case II, however, the bulk permittivity in the core sample in depth (z) direction was evidently lager than those in the core sample in horizontal (x) direction.

Based on an effective medium approximation theory, we could understand the measured bulk permittivity as a result of anisotropic cracks: The mixture of cracks in perpendicular and parallel directions to the impressed electric field was produced within the concentric crack area just below the impact carter, and the cracks in perpendicular directions to the impressed electric field was mainly produced outside of the concentric crack area (Figs. 1e and 1f).

Summary: Through the impact experiment, we measured a different bulk permittivity between in the core samples along depth (z) and horizontal (x) directions, which make it difficult to derived bulk density from the measured bulk permittivity (Figs. 2c and 2d). Based on the effective medium approximation theory, the cracks in parallel and perpendicular directions to impressed electric field produced the different bulk permittivity. This study will be useful for revealing geological condition on the Moon and other planets based on radar sounding.

References: [1] Carrier et al. (1991), Lunar Sounce Book, Cambridge Univ. Press, New York, 475-594. [2] Ishiyama et al. (2013), J. Geophys. Res. Planets, 118. [3] Kärkkäinen et al. (2000), IEEE Transactions on Geoscience and Remote Sensing, 38, 3, 1303-1308.

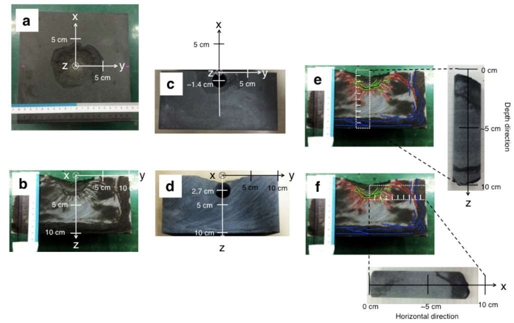

Fig. 1 Photos of basalt target impacted at the projectile's velocities of 5.638 km/s. The origin of coordinate system is at the center of the impact crater. (a) Artificial crater on impacted target surface (~8.5 cm in diameter). (b) Cross-section of basalt target cutting along yz-plane. Water saturated along the crack, and showed the crack distribution. (c) Location of core sample drilled along depth direction (x = −1.4 cm, y = 0 cm, ~1 cm < z < 10 cm). (d) Location of core sample drilled along horizontal direction (~0 cm < x < 8.2 cm, z = 2.7 cm, y = 0 cm). (e, f) Locations of concentric (green), radial (red), and liner (blue) cracks superposed on Fig. 1b. (e) Comparison of core sample drilled along depth (z-axis) direction with the crack distribution seen at a surface (y = −1.4 cm, x = 0 cm, 0 cm < z < 10 cm) (i.e., the white dashed rectangle). The electric field for measurement was impressed along z-axis. (f) Comparison of core sample drilled along horizontal (x-axis) direction with the crack distribution seen at a surface (0 cm < y < 10 cm, z = 2.7 cm, x = 0 cm) (i.e., the white dashed rectangle). The electric field for measurement was impressed along x-axis.

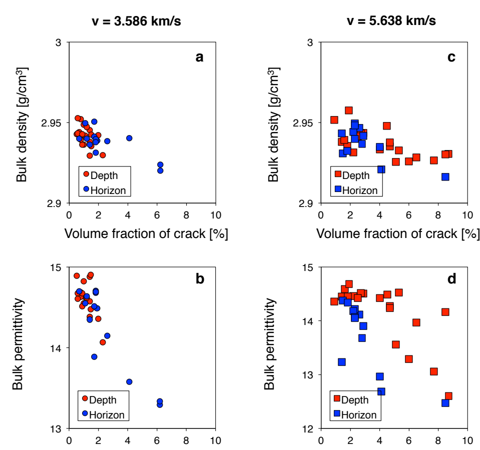

Fig. 2 The bulk density and bulk permittivity as function of amount of crack (a, b) in the projectile's velocity of 3.586 km/s and (c, d) in the projectile's velocity of 5.638 km/s. The red and blue colors show that the core sample is along depth (z) and horizontal (x) directions, respectively.