ANALYSIS OF DARK RINGS AROUND LUNAR CRATERS USING CLEMENTINE IMAGING DATA.

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Introduction: The characteristics and distribution of impact melt provide an important information for cratering mechanics. Lunar craters are good targets because the distribution of impact melt are well preserved and can be investigated by remote sensing. Dark rings, which surround large Copernican-age craters, have been observed by Earth-based and spacecraft-based images [1-3]. These dark rings are associated with impact melt. We investigated the distribution of impact melt around seven large fresh Copernican-age craters (Vavilov, Tycho, King, Jackson, Ohm, Crooks and Olbers A) at lunar highland by using Clementine UV-VIS high-resolution multispectral mosaic images.

Spatial setting and spectral properties: Fig. 1 is a Clementine mosaic image of Tycho. In a single band (750 nm) image, there is a dark ring around the crater rim. The dark ring extends about 0.8 crater diameter from the rim. The material of the dark ring is the uppermost ejecta except for some ray material. A small crater (D = 500 m) superimposed on the dark ring about 38 km north of Tycho has a bright ejecta, so the maximum thickness of dark ring material can be estimated 50 m based on depth/diameter relationship [4].

A color composite images with Red = 750/415 nm, Green = 750/950 nm and Blue = 415/750 nm reveals that the rings have high 750/410 nm ratio and low 750/990 nm ratio (Fig. 2). These characteristics are same as results of previous studies [1-3]. The line profile of albedo shows a chevron shape of the ring outside the rim (Fig. 3). There is a good reciprocal relation between albedo and 750/415 nm ratio. The darkest zone of the ring is apart from the crater rim about 0.5 crater diameter. It is suggested that the dark ring material is buried by regolith that crumble from a slope of the rim. The spectral properties of the dark rings are in accordance with those of glass. Laboratory results showed that spectra of fused glasses become darker and redder than those of their crystalline parents [5-8]. It is argued that thin veneers and splashes of Fe-bearing glass are contributor to the dark rings [2].

Effects of crater size: The dark rings of all craters extend 0.6 - 0.8 crater diameter from the rim, regardless of crater diameter (Table 1). On the other hand, the distinctness of the dark ring increases with crater diameter. The rings of smaller craters Crooks (D = 49 km) and Olbers A (D = 43 km) can be recognized in single band images, but in color composite images and line profile plots they are indistinct.

The distinctness of the ring probably reflects a glass content of the ring material. Theoretical calculation shows that a volume of impact melt is proportional to the power of 3.85 of the transient cavity diameter [9]. Accordingly, the glass content of the ejecta increases with the diameter. This trend is consistent with observed appearance of the dark rings. Giordano Bruno (D = 22 km) has no apparent dark ring in spite of its young age [3]. Giordano Bruno is too small to generate impact melt enough to form a dark ring.

Asymmetric deposition of dark rings: Most of sample craters have asymmetrical rings. We investigated the relationship between asymmetry of the rings and downrange directions of oblique impacts inferred from ejecta distributions and crater shapes (Table 1). The most evident directions of the rings seem to be nearly perpendicular to the downrange directions at four craters (Vavilov, Tycho, Jackson and Olbers A) with the exception of Ohm. These asymmetry is probably due to oblique impacts. This deduction also means that the dark ring material is transported by the same mechanism for other ejecta.

Estimation of impact melt volume: Melt volume of dark ring material can be estimated from the total volume of the dark ring material with its glass content. Comparison between telescopic NIR spectra for the dark rings and laboratory samples suggest that dark rings may consist of approximately equal amounts of glass and crystalline material [7]. For the dark ring of Tycho, the estimated volume of impact melt in its dark ring material is about 7×10^2 km^3. This amounts to about 30 % of the total volume of impact melt, which was theoretically estimated [9]. Although this is a rough estimation, it is almost same order of the ejected melt volume given by the z-model of cratering mechanics [9]. It is also consistent with the estimation for a terrestrial crater, Ries; its glass volume in fallout ejecta is 20 % of total amount of the impact melt [10].

Table 1. Data for lunar craters with dark rings.

Crater Name	Crater diameter [km]	Inferred downrange direction	Most evident dark ring	Width of dark ring normarized by diameter
Olbers A	43	SE or NW	NNE	0.7
Crookes	49	-	NE	0.7
Ohm	64	SW	NNE	0.7
Jackson	71	SE	NE	0.8
King	77	-	N	0.8
Tycho	85	E	N	0.8
Vavilov	99	SW or NE	ESE	0.6

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Conclusion: The dark ring is a common feature of fresh large (D > 40 km) lunar craters. Their spectral properties indicate that the dark ring material contains glassy impact melt. The mode of occurrence suggest that the impact melt are dispersed from a crater with other ballistic ejecta and rapidly quenched. The dark ring material deposits as the uppermost ejecta, which is mixture of crystalline fragments and quenched glass. Fallout suevite at the outside of the rim of Ries crater has the same mode of ejection and emplacement as that the lunar dark ring material has [10]. Suevite can be considered as the dark ring material.

References: [1] Smrekar S. and Pieters C.M. (1985) *Icarus*, **63**, 442-452. [2] McEwen A.S. et al. (1993) *JGR*, **98**, 17207-17231. [3] Pieters C.M. et al. (1994) *Science*, **266**, 1844-1848. [4] Melosh H.J. (1989) *Impact Cratering: A Geologic Process.* Oxford University Press, 245 pp. [5] Moroz L.V. et al. (1996) *Icarus*, **122**, 366-382. [6] Tompkins S. et al. (1996) *LPS*, **XXVII**, 1335-1336. [7] Tompkins S. et al. (1997) *LPS*, **XXVIII**, 1441-1442. [8] Ohtake M. and Otake H. (1998) *Abstract for AGU fall meeting*, 14599. [9] Cintala M.J. and Grieve A.F. (1998) *Meteoritics & Planet. Sci.*, **33**, 889-912. [10] Pohl J. et al. (1977) *Impact and Explosion Cratering*. Pergamon Press, pp. 343-404.

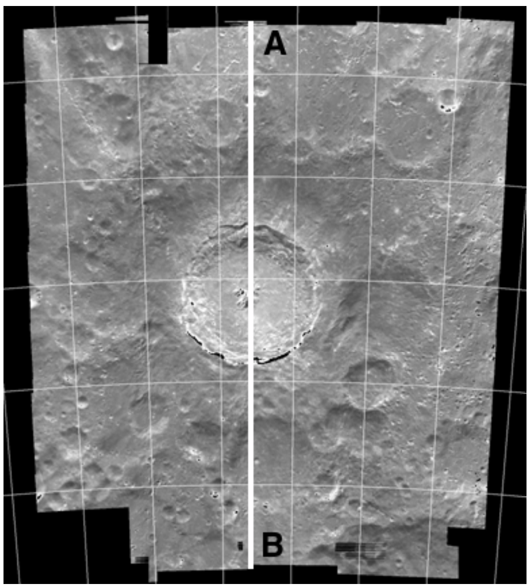

Fig. 1. Mosaic of Tycho (750 nm band). The grid interval is 2 degree. The line indicate the location of the profile analysis presented in Fig. 3.

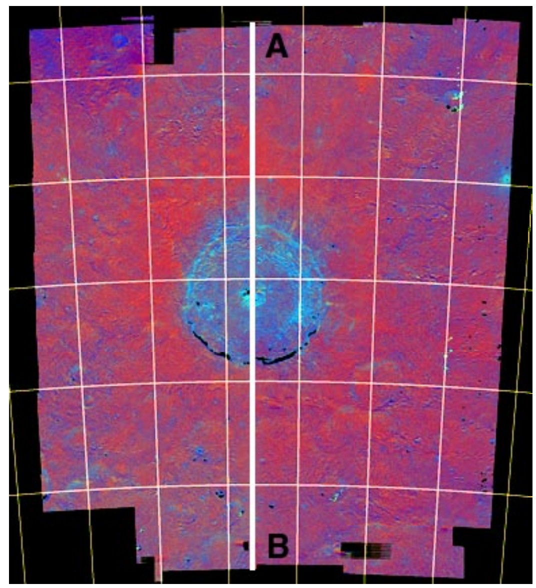

Fig. 2. Color composite image of Tycho.

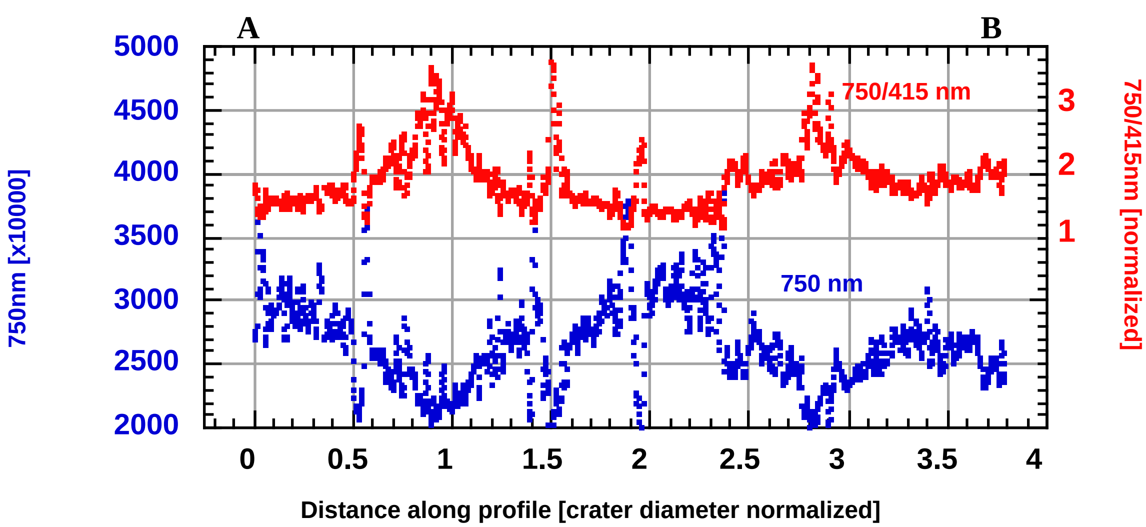

Fig. 3. Profiles of 750 nm albedo and 750/415 nm ratio across Tycho.