MORPHOLOGICAL ANALYSES OF TYCHO CRATER WITH KAGUYA DATA. N. Hirata[1], J. Haruyama[2], M. Ohtake[2], T. Matsunaga[3], Y. Yokota[2], T. Morota[2], C. Honda[2], Y. Ogawa[3], T. Sugihara[4], H. Miyamoto[5], H. Demura[1], and N. Asada[1], [1]The University of Aizu, Ikki-machi, Aizu-Wakamatsu, Fukushima, 965-8580, Japan, [2]The Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, [3]National Institute for Environmental Studies, [4]Center for Deep Earth exploration, Japan Agency for Marine-Science and Technology, [5]The University Museum, The University of Tokyo. Corresponding author's e-mail address: naru@u-aizu.ac.jp

Introduction: We investigated a large lunar crater Tycho with KAGUYA/LISM data to reconstruct the impact event forming the crater from distributions of its ejecta and other associated features. The asymmetric distribution of the ray system of Tycho is widely accepted as a piece of evidence that it was formed by an oblique impact in the east-to-west direction [1]. Several researchers [2-5] described other morphological features of Tycho with data from previous missions or projects, and discussed relationships between them and effects of the oblique impact. Although their conclusions are generally consistent with the west-to-east oblique impact, comprehensive discussions of various features have not been published. Moreover, we find inconsistency between observed alignments of crater features and the proposed impact direction. A group of researchers pointed out that slumping structures on the inner wall are most developed in the uprange direction [3], but the maximum slumping structure isn't found in the western inner wall, but in the southwestern inner wall [2].

Used Data: A high-resolution mosaic image composed of data from Terrain Camera (TC) [6], and a 9-band cube mosaic image of Multiband Imager (MI) [7], are used for our analyses. The spatial resolutions were 10 m/pixel for TC, 20 m/pixel for MI-VIS, and 60 m/pixel for MI-NIR. The MI mosaic is an image cube of MI-VIS and MI-NIR, and each image plane is resampled to 20 m/pixel. A digital terrain model (DTM) derived from TC stereo pairs was also employed. The Clementine DIM was to supplement the other data. All data are converted to the Lambert azimuthal equal-area projection, with the projection center at the crater center.

Ray, Distal Ejecta and Secondary Craters: The global DIM of Clementine UVVIS is suitable for examining the distributions of the ray system, distal ejecta and secondary craters of Tycho. These features are highly visible in the Clementine DIM as bright units. They expand from the crater in a fan-shape toward the east. On the western side of the crater, two major rays expand symmetrically to the northwest and southwest about the west-east axis. A forbidden zone of the distal ejecta is found on the western region of the crater between the two rays.

Ejecta Blanket: The extent of the ejecta blanket is mapped on the TC mosaic. The borderline generally agrees with those given by previous results [8], and exhibits a fan-shaped distribution with weak bilateral symmetry similar to the distal ejecta. More detailed descriptions of the ejecta blanket features are presented below.

Ejecta units. Surfaces of the ejecta blanket have three contrasting morphologies. The first morphology is the most common unit on the blanket and consists of radial streak patterns. It corresponds to the radial rim material in the USGS geologic map [8]. The radial pattern gradually changes to chains of hummocks near the border of the ejecta blanket, and transitions into secondary craters on the outside of the blanket. The second morphology is dominated by numerous radially flow features (flow ejecta). The third morphology is characterized by fine wrinkles parallel to the crater rim (wrinkled ejecta). The flow ejecta, which corresponds to the blocky rim material in the USGS geologic map [8], are most developed on the northern sector of the ejecta blanket. Flow features on the flow ejecta would have been formed by outward streams of impact melt materials, and many impact melt ponds are associated with this kind of ejecta. The wrinkled ejecta, in contrast, seem to be "dry" or have less molten materials except for isolated melt ponds. Many boulders are found on the wrinkle ejecta. The pattern of wrinkles extends continuously in the terrace zone of the inner wall of the crater. This appearance strongly suggests that the wrinkles were formed before the modification stage of the cratering process. The shorelines of the isolated melt ponds on the wrinkled ejecta also follow to the wrinkle pattern, so the melt ponds should be the last deposits of the cratering process. The wrinkled ejecta are most developed on the north-eastern and south-eastern sectors of the ejecta blanket.

Melt Ponds. The melt ponds distribution on the ejecta blanket exhibits a bilateral symmetry about the east-west direction [9]. The radial distribution plot of the melt ponds has two distinct V-shaped peaks at ENE and ESE. A cluster of large ponds on the eastern rim contributes to this distribution. When the eastern pond cluster is excluded, the third peak at the northern sector becomes remarkable in the radial distribution plot. The northern sector of the ejecta blanket is morphologically characterized with the flow ejecta unit and a swarm of small ponds. The DTM indicated that this sector forms a conspicuous plateau, although the rim heights are rather lower than adjacent sectors. A forbidden zone of the melt ponds is found at the south-western sector.

Crater Interior: Tycho is a typical peak crater. It has terraced inner walls, a flat floor filled with impact melt, and a central peak.

Terrace Slumping and Central Peak. As noted in a previous manuscript, the south-western part of the inner wall has the maximum wall slumping [2]. It is also notable that the central peak of Tycho is slightly elongated in the NW-SE direction, which is perpendicular to the wall slumping structure.

Melt Ponds. Melt ponds are also found on the terrace zone, and they also exhibit the bilateral symmetry about the east-west direction similar to the rim ponds. Their radial distribution plot also has two peaks, but the separation angle of the peaks is wider than that of the rim ponds.

Impact Melt Sheet. Even though the slumping structures and the central peak have a SW-NE orientation, the crater floor has a clear east-west dichotomy. The western half of the floor is hummocky and declined to the east, whereas the eastern half is more smooth and levelled. This appearance suggests that a thick sheet of impact melt covers the crater floor only on the eastern half. Comparing surface roughness of both halves, the melt sheet on the eastern half is estimated to be 100 m thick. This is only one third of the model thickness estimated with the differential melt-crater scaling [10].

Discussions: These analyses have indicated three axes of symmetric distributions of the ejecta units and other features associated with Tycho: an east-west axis for the distal ejecta, the ejecta blanket and the melt ponds; a north-south axis for the small melt ponds, the flow ejecta and the crater floor; and a southwest-northeast axis for the forbidden zone of the melt ponds, the inner wall slumping and the central peak. The first axis is the dominant one, and its associated features are ejecta at the early stage of impact cratering. As effects of an oblique impact should dominate more strongly in the earlier stage [11], the impact that formed Tycho is surely an oblique impact from west to east. The rest two axes would reflect other factors, such as the pre-impact topography or subsurface structures are possible.

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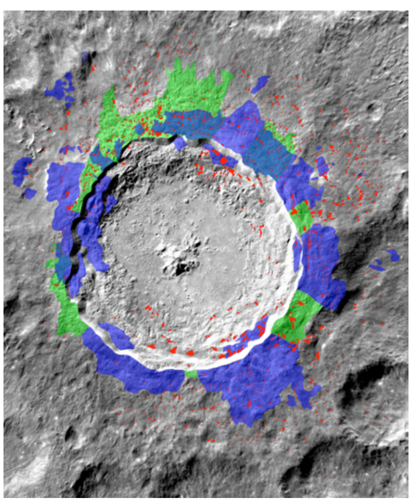

Fig.1. Distributions of the flow ejecta (green), the wrinkled ejecta (blue) and the melt ponds (red) of Tycho.

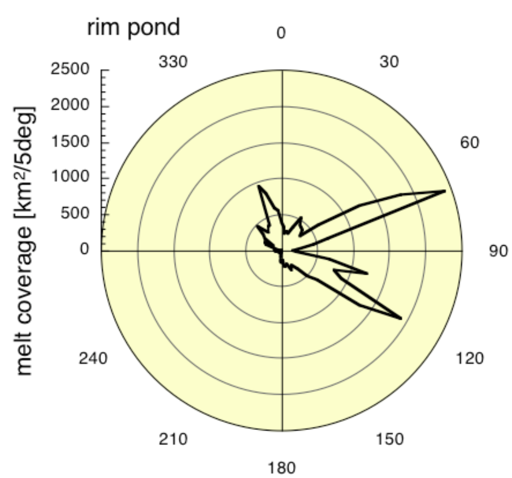

Fig.2. Azimuthal distribution of the melt ponds on the ejecta blanket of Tycho.