Space weathering of quasi-circular depressions on Itokawa and its orbital evolution

*ERI TATSUMI[1], Seiji Sugita[1]

1. The University of Tokyo, Department of Earth and Planetary Science

Introduction: The orbital evolution of asteroids is important for understanding both the current distribution of asteroids and the mass flux to terrestrial planets. Near-Earth objects, such as Itokawa, Ryugu and Bennu, are estimated to have come from the asteroid main belt, through changing their orbits by the Yarkovsky effect to resonances with Jupiter where asteroids are scattered and removed from the main belt to such as near-Earth orbit. Spacecraft explorations to asteroids have obtained detailed morphologies and spectral properties of near-Earth asteroids. In particular, observations by AMICA (Asteroid Multi-band Imaging Camera) onboard the spacecraft Hayabusa revealed that the asteroid Itokawa exhibit of heterogeneous reddening and darkening, strongly suggesting space weathered on this asteroid [1]. The different degree of space weathering is likely to reflect different lengths of exposure time to space. Thus, the time scale of surface modification processes on asteroids could be estimated from the degree of space weathering. In this study, we analyze the degree of space weathering for quasi-circular depressions on Itokawa, which may be impact origin [2]. Finally, we discuss the residence times of Itokawa both in the main belt and the near-Earth orbit.

Method: Previous work on the principal component analysis of spectra obtained by AMICA suggested that, the first principal component (PC1) of Itokawa is possibly the trend of space weathering [3]. Thus, we used PC1 score to assess the degree of space weathering on Itokawa. Using high-resolution images taken from lower altitudes than the home position, we generated space weathering maps of Itokawa. After the PC1 score of each circular depression is derived, the PC1 scores are converted into relative exposure time based on the laser irradiation experiments on Olivine and LL chondrites [4,5]. The exposure time might indicate the lower limit of each circular depression.

Results and Discussions: The highly space weathered quasi-circular depressions mostly have fresh rims compared to their old floors, while the moderately weathered ones usually have the rims weathered similarly as the floors. This suggests that the rims gradually collapsed and moved towards the floors of depressions. This observation supports the crater modification process by seismic shaking by small impacts on asteroids [6]. Furthermore, we found that the age distribution of large quasi-circular depressions (>100 m) is not uniform, while that of small ones is relatively uniform. More specifically, all the depressions larger than 100 m turned out to be older than the average exposure time of Itokawa. This may reflect the change in the impact rate on Itokawa. For example, the impact energy flux in the main belt is ~50 times that in near-Earth orbits. In other words, the number of craters formed in a unit time is 50 times larger in the main belt than in the near-Earth orbit, if the impact energy dominates the crater size. The orbital change from the main belt to the current orbit may explain the lack of fresh and large circular depressions on Itokawa.

Our previous study suggests that the formation of large circular depressions on Itokawa might take 9.9-33 Myr in the main belt [7]. Other previous studies suggested the space weathering time scales on Itokawa, such as <8 Myr [8] and ~1.5 Myr [9] from CRE ages of the sample analyses and <10 Myr [3] and 2-8 Myr [10] from the spectral analyses. All of these estimates are based on the solar ion flux at the near-Earth orbit (~1 AU). Although the space weathering rate in the inner main belt is approximately 4 times smaller than at the current orbit of Itokawa, the residence time in the main belt on the order of 10^7 yrs based on the number density of large craters might received enough space weathering effect as previous sample analyses and spectral analyses suggested. That is, the residence time of Itokawa in the near-Earth orbit is possibly very short (10^4-10^5 yr) as the number density of small and fresh craters suggests.

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