論文の内容の要旨

論文題目　Geological and statistical analysis of craters on Ganymede and Callisto: Implications to the sources of their impactors

（ガニメデおよびカリストのクレーターに関する地質学的・統計学的検討:クレーターを形成した衝突体の起源の推定）

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Chapter 1 Background

Impact craters record the history of a planetary body after its formation and give insights into the evolutionary history of the solar system. Most of our understanding about ages of planetary surfaces, including the sequences of geologic activities on a planetary body and the previous impact events of the solar system, comes from the analysis of crater statistics and morphology due to the lack of returned samples.

Until now, we have obtained considerable knowledge about the impact cratering situations of the inner solar system by observations, experiments and modeling [1]. Beginning with the crater counting on the Moon, crater chronology was established with the assistance of Apollo rock samples' calibration. With the basic assumption that the similar impactor flux of the inner solar system, the crater-chronology concept has been extrapolated for estimating the absolute ages on Mars, Mercury and Venus. In addition, owing to the booming space exploration during the last decades, the unprecedented high resolution images lead to a highly detailed and complete cratering counting.

Our understanding about the cratering situations of the outer solar system is, however, still limited for the following aspects: (1) the image coverage and resolution of the outer solar system are unsatisfactory due to the small numbers of spacecraft visiting; (2) the primary sources of impactors on each satellite are still uncertain and (3) crater chronology on the outer solar satellites was established by the assumption of similar impact history to the inner solar system, while the actual impact cratering situations are not necessary the same as those of outer solar system.

In order to realistically understand the impact history of the whole solar system, it is fundamental to investigate the impact craters on the outer planetary bodies in a more detailed way. Therefore, I did geological and statistical analyses on impact craters of icy satellites by studying the image data obtained by spacecraft. Specifically, I focused on the crater-density asymmetry of various crater morphologies on Ganymede and Callisto, two of the largest outer solar satellites, to investigate the geologic processes and derive the possible sources of impactors on Jovian system.

Chapter 2 Impactor sources of the outer solar system

Previous works indicate that impactors on the outer solar system mainly come from the following two sources: (1) heliocentric (centered by the Sun) comets, and (2) planetocentric (centered by the planet) debris. Heliocentric comets are further classified into ecliptic comets, which mainly come from Kuiper belt, and nearly isotropic comets (NICs), which mainly come from Ooct cloud and Halley-type. Most of the impactors for large craters on Jovian satellites are currently recognized to be originated from ecliptic comets [2, 3].

For a synchronously rotating satellite, the degree of apex-antapex cratering asymmetry is an important indicator to determine the sources of impactors. The preferential impacts of heliocentric comets on the leading hemisphere should cause the density of impact craters decrease from apex (the center of leading hemisphere) to antapex (the center of trailing hemisphere) of the motion. As a result, a strong decreasing apex-antapex asymmetry is theoretically expected under the assumption of ecliptic comets origin. However, none of the observations on the outer solar satellites show such a strong tendency by now. On the other hand, ray craters (Figure 1a-c), the impact craters surrounded by radial ejecta blankets (both brighter and darker), are recognized to be the youngest features on a planetary body [4, 5]. Therefore, the distribution of ray craters could serve as a more accurate indicator for studying the sources of recent impactors than that of all craters.

Chapter 3 Geological and statistical analysis of craters

In this study, I measured the locations and diameters of ray craters, rim deposit craters, all impact craters (Figure 1a-d) as well as the related areas by using the global mosaics of Ganymede and Callisto with a resolution of 1 km/pixel. Because identifications of crater rays are sensitive to photographic conditions, I carefully examined the raw images of both Voyager and Galileo data, and excluded the images of either emission angle > 85° or solar incidence angle > 70°. Considering the resolution and coverage of the raw images, I only measured the ray craters of > 10 km in diameter between latitudinal ranges of 70°N-70°S and within the regions of resolution higher than ~4.0 km/pixel. Ultimately, I obtained unbiased density distributions of ray craters on Ganymede and Callisto corresponding to angular apex distances, terrain types and resolutions.

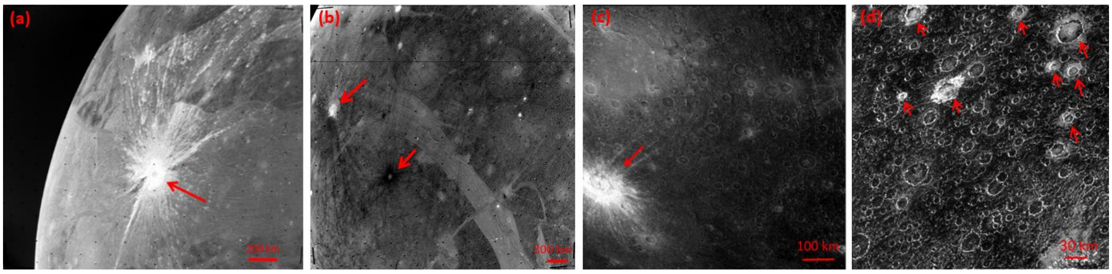

Figure 1. (a) Bright and (b) Dark ray craters on Ganymede, (c) Bright ray and (d) rim deposit craters on Callisto

Chapter 4 Cratering asymmetry on Ganymede

I identified a total of 202 ray craters (D > 10 km) (Figure 2a), 27 dark ray craters (20 of them larger than ~6 km), along with 5335 all craters (D > 10 km) (Figure 2b) on Ganymede. Major results include: 1) the comparison between dark and bright terrain show that bright ray craters are highly concentrated on the bright terrain of Ganymede, while dark ray craters are opposite. 2) Apex-antapex asymmetry exists. For example, for large craters (D > 25 km) on the bright terrain, the densities of both bright ray craters and all craters (D > 10 km) have an modest apex-antapex asymmetry, while for small craters (10 km < D < 25 km) on the bright terrain, only the densities of all craters maintain the asymmetry. In contrast, neither the large nor small craters show asymmetry on the dark terrain. 3) Latitudinal dependence exists. Both bright and dark ray craters on the dark terrain are highly concentrated at low latitudes.

Chapter 5 Cratering asymmetry on Callisto

I identified a total of 57 bright ray craters (D > 10 km), along with 279 rim deposit craters (D > 10 km) (Figure 3a) on Callisto. My findings include: 1) Apex-antapex asymmetry exists for large ray craters (D > 2 km) (Figure 2b) which exhibit pronounced decreasing tendency with increasing angular apex distances (20-160°). In contrast, the densities of combined ray and rim deposit craters (D > 25 km) (Figure 3c) also shows modest asymmetry (although with a lower degree), while the small ones exhibit no asymmetry. 2) The comparison between Ganymede and Callisto shows that the degree of asymmetry of ray craters on Callisto is nearly identical to that on the bright terrain of Ganymede. In addition, the apparent retention time for rays on Callisto is between the retention time of crater rays on the dark and bright terrains of Ganymede.

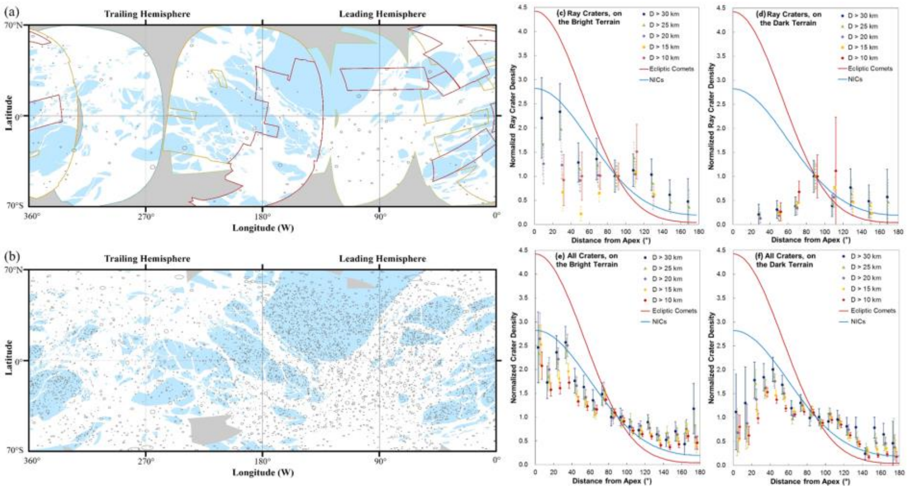

Figure 2. The distribution of (a) bright ray craters (D > 10 km, > 15 km, > 20 km, > 25 km, and > 30 km) in terms of the corresponding image resolution, and (b) all craters (D > 10 km) for Res< 4.0 km/pixel of Ganymede. Normalized crater densities of (c) ray craters on the bright terrain, (d) ray craters on the dark terrain, (e) all craters on the bright terrain, and (f) all craters on the dark terrain in terms of the corresponding image resolution.

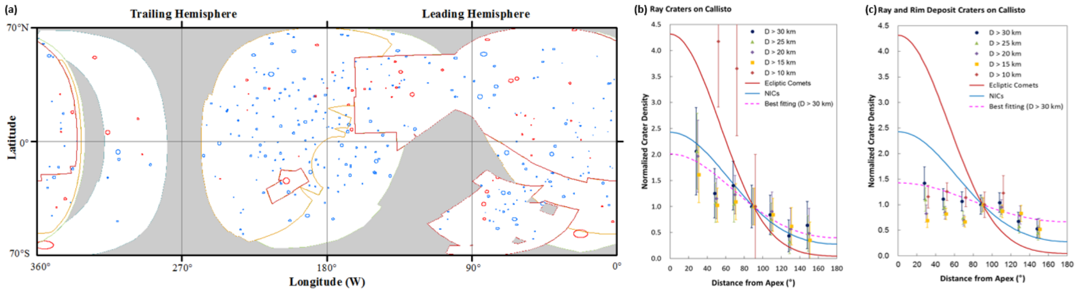

Figure 3. The distribution of (a) bright ray and rim deposit craters (D > 10 km, > 15 km, > 20 km, > 25 km, and > 30 km) in terms of the corresponding image resolution of Callisto. Normalized crater densities of (b) ray craters and (c) combined ray and rim deposit craters in terms of the corresponding image resolution.

Chapter 6 Implications to surface alterations and impactor sources of Jovian system

I interpret that the distribution differences of ray craters between bright and dark terrains of Ganymede come from preferential thermal sublimation on the dark terrain, while the distribution differences between large and small ray craters suggest that small ray craters are more readily to be erased by some surface modification processes, such as magnetospheric sputtering and micrometeorite gardening. Comparing to the dark terrain of Ganymede, the longer retention time of ray craters on Callisto suggests that Callisto suffered relatively milder surface alterations.

On the other hand, all of the four crater populations (D > 25 km) in this study, including (1) ray craters and (2) all impact craters on the bright terrain of Ganymede, (3) ray craters, and (4) combined ray and rim deposit craters on Callisto, exhibit much lower degree of asymmetry than the theoretical estimation for ecliptic comets. Therefore, I propose that nearly isotropic comets, instead of ecliptic comets, may be the dominant impactors on Jovian system, at least for the large craters (D > 25 km).

Chapter 7 Summary and future work

In this study, I did a detailed study of the distribution of various crater types on Ganymede and Callisto, and proposed that nearly isotropic comets may be the dominant impactors for large craters on Jovian system. These results strongly request revisions of previous estimates in surface ages and reconsideration of the dynamics of impactor populations of Jovian satellites.

References

[1] Neukum, G., 1984. Meteorite bombardment and dating of planetary surfaces. Doctoral Thesis.

[2] Zahnle, K., Schenk, P., Sobieszczyk, S., et al., 2001. Differential cratering of synchronously rotating satellites by ecliptic comets. Icarus 153(1), 111-129.

[3] Zahnle, K., Schenk, P., Levison, H., et al., 2003. Cratering rates in the outer Solar System. Icarus 163(2), 263-289.

[4] Passey, Q. R., Shoemaker, E. M., 1982. Craters and basins on Ganymede and Callisto-Morphological indicators of crustal evolution. In Satellites of Jupiter, pp. 379-434, Univ. of Arizona Press, Tucson.

[5] Shoemaker, E. M., Lucchitta, B. K., Wilhelms, D. E., et al., 1982. The geology of Ganymede. Satellites of Jupiter pp. 435-520, Univ. of Arizona Press, Tucson.