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論文審査の要旨及び審査員

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論文審査の要旨（2000 字程度）

The thesis is entitled "Establishing the model surface age of Saturn's regular satellites and major chronostratigraphic events on Enceladus" and contains 7 chapters and 3 appendices. This work combined research on the modelled crater chronologies of Saturnian regular satellites and the global geological history of Enceladus. The author established the outer Solar System's crater chronology through impact crater analysis and numerical N-body simulations, considering giant planet migration and refined estimation of the primordial planetesimal disc. Applying various impactor and crater size-frequency distributions, the author calculated surface ages for cratered plains on Mimas, Enceladus, Tethys, Dione, and Rhea. The study included a comprehensive global crater count and analysis of geomorphologies to derive the Enceladus crater production function, enabling precise calculation of its global surface age and exploration of its geological history.

In Chapter 1, “Introduction”, the author explored the historical impact rate on giant planets and their regular satellites, drawing from previous dynamic studies. The overview included calculating surface ages for Saturnian satellites' icy crust through crater dating. Limitations in previous work, such as assumptions about crater chronology (cumulative projectile flux through time) and crater size-frequency distribution (statistical relationship between crater diameters and their frequency of occurrence), were highlighted. The author emphasized the need for a tailored approach due to the unique dynamics and conditions of icy satellites in the outer Solar System. The breakthrough in the thesis lies in acquiring the crater chronology and size-frequency distribution catered for icy satellites to enhance age estimation accuracy.

In Chapter 2, "Outer Solar System: Evolutions and Simulation", the author delineated the parameters of the N-body simulations. The initial focus was on simulating giant planet migration to replicate 4.5 billion years of outer solar system evolution. However, due to the low expected impact probabilities of satellites, there were limitations in impact resolution. The author proposed and ran a batch with cloned planetesimals, optimizing computational resources while preserving the model's accuracy. This approach enhanced impact resolution, enabling the construction of a precise 4.5 Gyr crater chronology.

In Chapter 3, "Giant Planets and Comets: Impact Rate", the author ensured the simulations align with the current outer solar system conditions. Calibration was performed based on the constrained impact rate on Jupiter, integrating results from prior studies. The author calculated initial planetesimal numbers, defined their size-frequency distribution, and assessed their rate of decline. Simulation results indicated that, after 4.5 Gyr, only 0.31% of scattered disc objects remained, suggesting an initial count of 6.4 billion objects over 10 km in diameter. Impact count simulations over the last 1 Gyr estimated a current Jovian impact rate of 1.57×10^{-3} per year for comets larger than 1 km in diameter.

In Chapter 4, "Icy Satellites: Crater Chronology and Absolute Surface Ages", the author introduced an improved approach to constructing a crater chronology, extending the chronological curves much further to recent times and enhancing accuracy. With the improved chronology, the author calculated the highest expected crater density for each Saturnian icy satellite, assuming a solidified surface and retention craters from 4.5 billion years ago. To visually convey how to calculate the surface ages, the author plotted and compared the crater size-frequency measurements with age-isochrons — representing distributions for surfaces with varying ages. The author derived best-fit surface ages through a least-square fitting, addressing discrepancies with previous studies and affirming the updated ages' accuracy.

In Chapter 5, "Enceladus: Untangling its long history of activity”, the author expanded the study on Enceladus. Calculating ages not only for a specific cratered plain, but across an extensive, nearly global area, the author surveyed Enceladus using publicly released Cassini images, reporting ages on over 80% of its surface. Despite the absence of outer Solar System satellite crater production functions, this study introduced a comprehensive crater count method, establishing a polynomial function for a new Enceladus crater production model. This model, combined with crater chronology, enabled age determination for surface units. The author discussed how crater dating complemented previous geomorphological studies, offering insights into crater asymmetry, impact population, satellite formation, and Enceladus' tidal history.

In Chapter 6, "Future work", the author outlines the vision for advancing and extending the current approach to the regular satellites of Jupiter and Uranus and crater chronology modelling to the inner solar system. The concluding remarks and project summary are presented in Chapter 7.

The thesis synthesized knowledge from the dynamic evolution of the outer Solar System and remote sensing of satellites' ice crusts to determine the ages of Saturn's regular satellites and diverse terrains on Enceladus. Its interdisciplinary and innovative approach is judged to be of sufficient quality for the degree of Doctor of Science.