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論文審査の要旨（2000 字程度）

The thesis is entitled "New Insights on the Formation of the Terrestrial Planets" and contains 4 chapters and 3 appendices. It is a combination of 2 research projects on the formation pathway of the terrestrial planets and other planetary bodies in the inner Solar System. The author used numerical N-body simulations coupled with constraints from cosmochemistry data (meteorite isotopic composition and elemental abundances) to determine which of the two possible formation pathways – *pebble accretion* and *planetesimal accretion* – is more likely. By comparing the outcomes obtained from the simulations with meteorite data, the author concludes that the pebble accretion pathway is difficult to reconcile with cosmochemistry constraints whereas the planetesimal accretion pathway is more promising if certain conditions are fulfilled.

In the introduction chapter the author first describes the classical model and its critical problem, followed by describing subsequent models proposed to address the flaw. The classical model and models that stem from it are based on the conventional understanding that the terrestrial planets grew through a series of accretion processes involving increasingly massive planetesimals. This understanding is being challenged by several recent studies showing that the accretion of smaller-sized objects termed 'pebbles' can also reproduce the mass and orbits of inner Solar System objects, thus bringing the question of whether the terrestrial planets did grow mostly by pebble accretion into the spotlight. The author then proceeds to discuss 3 observations and trends from meteorite data: (1) the isotopic dichotomy in the Solar System, (2) the isotopic heterogeneity among meteorites in the non-carbonaceous meteorite group, and (3) the apparent correlation between the isotopic compositions of Earth, Mars and Vesta and their distance from the Sun. These cosmochemistry observations can distinguish the more likely formation pathway and are thus employed in the thesis as additional constraints for the numerical simulations.

In Chapter 2 the author presents the outcome of applying the pebble accretion model to the inner Solar System. The author first reports the outcome of simulations studying only a single planetesimal and subjected to an incoming pebble flux originating from the outer Solar System to understand how factors such as initial planetesimal mass, the planetesimal's location in the disc and pebble fragmentation effects at the snow line influences the final mass of the planetesimal. The author found that there are two possible outcomes, the planetesimal is either in the settling regime where pebble accretion is efficient and the planetesimal accretes a lot of pebbles and grow large or it is in the geometric regime where pebble accretion is inefficient and the planetesimal does not grow at all. The transition between the two regimes is abrupt with a critical initial planetesimal diameter of roughly 300 km. If pebble fragmentation at the snow line is taken into account, planetesimals smaller than 300 km and located close to the Sun can become efficient at accreting pebbles.

To understand the effects of pebble accretion on a solid disc comprising many planetesimals located in the inner Solar System, the author carried out simulations testing a range of initial disc mass and gas disc temperature with a planetary seed located at 5 au that will grow to Jupiter. It was found that planetesimal discs containing many planetesimals larger than 300 km in diameter increase their mass by at least 200% while the discs with only planetesimals smaller than 300 km recorded mass increase of 0.3% to 300% depending on the gas disc's temperature and whether pebble fragmentation effects are in force. The substantial increase in disc mass contributed by outer Solar System pebbles implies that the isotopic composition of the inner Solar System would be replaced by that of the outer Solar System, inconsistent with the isotopic dichotomy. The maximum contribution of outer Solar System material to the composition of Earth and Mars is limited to 10% based on chondritic mixing models. In simulations where pebble fragmentation effects are disregarded, the mass increase in the planetesimal disc can be less than 10% the initial disc mass, but the downside is that these discs do not have sufficient mass to form the terrestrial planets via planetesimal collisions. The author thus concludes that pebble accretion is unlikely to be the major contributor to the growth of the terrestrial planets.

In Chapter 3 the author reports the results with a new and rather unexplored model, the depleted disc model, to form the terrestrial planets by planetesimal accretion. The terrestrial planets accrete most of their building material locally and that Vesta and two other asteroids have high probability of forming in situ in this model. The author concluded that this outcome can be consistent with cosmochemistry data if there was a difference in the isotopic composition of the solid material accreted by each of the terrestrial planets, and that the isotopic heterogeneity is not disturbed for example by the mixing of material in the disc.

The thesis synthesized knowledge from the fields of planet formation and cosmochemistry to answer whether the terrestrial planets grew by the accumulation of pebbles or planetesimals. It demonstrated the advantages of this approach as a possible way forward in studying the problem and therefore is judged to be of sufficient quality for the degree of Doctor of Science.