Review of doctoral thesis

Gravity and Magnetic Fields of Small Planets

by Kurosh Karimi

Kurosh Karimi's thesis focuses on the local assessment of internal structures through gravity potential analysis, with additional attention given to magnetic potential. The thesis also discusses the theoretical aspects of gravity and magnetic potentials using their gradient tensors. Apart from the introductory sections and conclusions, it comprises four published works in *Scientific Reports*.

The first chapter outlines the objectives and structure of the thesis and provides a brief overview of the techniques employed in the thesis for the gravity and magnetic fields analysis. It also shortly introduced datasets used in the thesis. The second chapter presents a chronological development and summary of the papers included in the thesis.

The third chapter is dedicated to the theoretical description of gravity and magnetic potentials, including their gradient tensors and the gradient tensor computations. It also explores the sensitivity of these potentials with respect to the distribution and assessment of gravity and magnetic anomalies. A key focus is the identification and correction of a previously published inconsistency in the evaluation of strike alignment by other authors.

Chapter Four (Article 1, *Distribution of Water Phase Near the Poles of the Moon from Gravity Aspects*) examines water distribution on the Moon's poles using gravity data. It suggests that ions from Earth's magnetotail may contribute to water deposits in the Moon's polar regions. The study identifies potential permafrost areas by analyzing gravity anomalies and strike angles, which might be important for future missions like NASA's Artemis Plan. The volume of water is based on back-of-the-envelope calculations. These assumptions could lead to significant variability and may require further validation. During the review of the water volume estimation section, I noted an oversight in the conversion, leading to a considerably lower estimate of water deposits. Despite this, Kurosh Karimi's gravity calculations and analysis in this chapter are well-conducted and demonstrate a good understanding of the methodology.

Chapter Five (Article 2, *Comparison Between the Geological Feature of Venus and Earth Based on Gravity Aspects*) compares the geological features of Venus and Earth using gravity models. The study focuses on areas like Venus' Lakshmi Planum and Earth's Eurasian-Indian Contact Zone to explore differences in geological processes and tectonic regimes. It finds that while Venus exhibits tectonic and volcanic activity similar to Earth, it lacks modern plate tectonics. By using methods developed for terrestrial studies, the paper successfully adapts these techniques to study Venus. This approach bridges planetary geology and Earth science, opening further research in comparative planetology.

Chapter Six (Article 3, *Formation of Australasian Tektites from Gravity and Magnetic Indicators*) investigates an alternative location of the parent impact crater responsible for Australasian tektites by analyzing gravity and magnetic data. Previous hypotheses have centred around Indochina, but this paper presents evidence supporting an alternative site in the Badain Jaran Desert in Northwest China. The study employs a wide range of geophysical data, including both gravity and magnetic parameters, to provide as robust analysis of the potential impact structure as possible. However, the study concludes that more investigations are needed to confirm the hypothesis. The study lays a strong foundation for future research but remains speculative until further investigations are conducted.

Chapter Seven (*Subsurface Geology Detection from Application of the Gravity-Related Dimensionality Constraint*, Article 4) introduces an innovative approach for estimating the depth of geological bodies using gravity-related dimensionality. The method's accuracy is validated with both synthetic and real lunar gravity data, demonstrating its robustness in estimating depth even under noisy conditions. When compared with the Euler deconvolution method, the new approach aligns with the results but offers more refined estimations. It requires minimal assumptions and is effective for various geological bodies and depths, making it valuable for both planetary and engineering applications. However, its performance in more general or extreme geological scenarios remains unclear to me.

Chapter Eight outlines the possible future directions for research, building on the findings and methodologies presented in the thesis.

From a technical perspective, the thesis would benefit from more careful editing and refinement of the language. The text references supporting information from the related articles; not all of this content is fully addressed in Chapter Three. Some additional figures and discussions are missing. The thesis frequently introduces or uses variables before they are defined or discussed, which can lead to confusion. Additionally, there are several unfortunate typographic errors: for example, equation (3) incorrectly uses $C_{n,m}$ and $S_{n,m}$ and later the disturbing potential T works with $\Delta C_{n,m}$ and $\Delta S_{n,m}$; equations (7-12) are missing contributions from $\Delta S_{n,m}$; and the dimensionality factor definition contains an incorrect divisor in the denominator. The compulsory sections in Czech reflect the fact that the author is not a native Czech speaker.

Summary Kurosh Karimi's thesis provides a thorough examination of local gravity and magnetic potential analyses for selected locations on Earth, Venus, and the Moon, demonstrating a solid understanding of the used methodologies. The research focuses on evaluating internal structures through gravity potential analysis, with additional attention to magnetic potential and their theoretical aspects. This work demonstrates Kurosh Karimi's development of essential skills not only in applied geophysics but also in integrating planetary science and modelling techniques. His ability to adapt terrestrial geophysical methods to the study of Venus and the Moon bridges key disciplines, demonstrating an interdisciplinary approach to planetary exploration. I recommend the thesis be accepted for the PhD degree.

Specific comments and questions for discussion

1. During the defence, please provide a more detailed explanation of the contributions made to each article included in the thesis.
2. How is the comb factor sensitive to the resolution of the gravity data evaluation grid and to the size of the square window? Can an analogy be drawn to using a comb factor to detect a circular-like faulting system, which could be particularly useful for identifying fault systems around craters? More generally, are image recognition techniques being utilized in the detection of subsurface features from gravity field data?
3. Given the lower resolution of current Venus gravity data, how do you think upcoming missions like NASA's VERITAS and ESA's EnVision will enhance future Earth-Venus comparisons, particularly in understanding Venus' geological features?
4. Article 2 tends to focus on specific interpretations of gravity data (e.g., mantle plumes vs. subduction). Could there be another possible explanation for the observed features on Venus? How does your interpretation align with possible plutonic squishy lid scenario Lourenço et al. (2020) or Ishtar Terra highlands formation novel scenario Capitanio et al. (2024)?
5. Are there alternative interpretations of the geophysical anomalies discussed in Article 3? Could other observations, such as seismic data, be used to strengthen the interpretation?
6. In Article 4, while the method successfully detects chosen geometrical features, there is a lack of detailed analysis regarding its performance in extreme or less typical geological scenarios. For instance, what is the effect of a tilted geometrical feature with a non-zero dip angle on the method's accuracy?

References

Capitanio, Fabio A. et al. (Aug. 2024). "Ishtar Terra highlands on Venus raised by craton-like formation mechanisms". In: *Nature Geoscience* 17.8, pp. 740–746. DOI: 10.1038/s41561-024-01485-3.

Lourenço, Diogo L. et al. (2020). "Plutonic-Squishy Lid: A New Global Tectonic Regime Generated by Intrusive Magmatism on Earth-Like Planets". In: *Geochemistry, Geophysics, Geosystems* 21.4, e2019GC008756. DOI: 10.1029/2019GC008756.

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