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Thermal Structure in the Volcanic Geothermal System of Changbai Mountain

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INTRODUCTION

The Changbai Mountain region, situated along the China-North Korea border, located at the Circum-Pacific Geothermal Belt. Owing to its extensive surface thermal manifestations (including widespread hot springs) (Yan et al., 2018) and active volcanic activity, it is recognized as a region with significant geothermal resource potential and represents a typical volcanic-type geothermal system.

Surface heat flow serves as a comprehensive quantitative indicator of the thermal state of the crust and lithosphere at the Earth's surface. The lithospheric thermal structure, a critical extension of heat flow studies, is one of the key factors governing the heat source mechanisms of geothermal resources. However, the lithospheric thermal structure beneath the Changbai Mountain area remains poorly constrained, and the characteristics of deep geothermal resource distribution are not well understood. This study aims to investigate the lithospheric thermal structure of the Changbai Mountain region. and clarify the regional heat source structure.

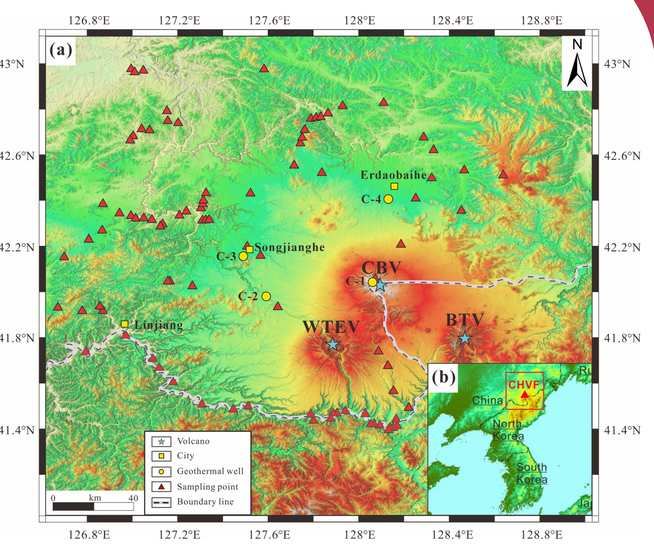


Figure 1. Topographic map of the Changbai Mountain region (Song et al., 2025)

METHODS

This study investigates the Changbai Mountain region through an integrated analysis of multiple geophysical datasets, including seismic profiles (Cheng et al., 2024), magnetotelluric data, gravity-magnetic data and Earth Thermodynamic Simulation (Gorczyk et al., 2018), to analyzing regional stratigraphic characteristics and establishing a three-dimensional geological model of the Changbai Mountain region. By combining newly sample measurements with existing published data, we developed a representative thermophysical property column for the lithosphere. Utilizing advanced numerical simulation techniques, we performed 3D thermal conduction modeling to derive the spatial temperature distribution and surface heat flow characteristics. Finally, we delineated the heat source structure and characterized the lithospheric thermal structure of the region.

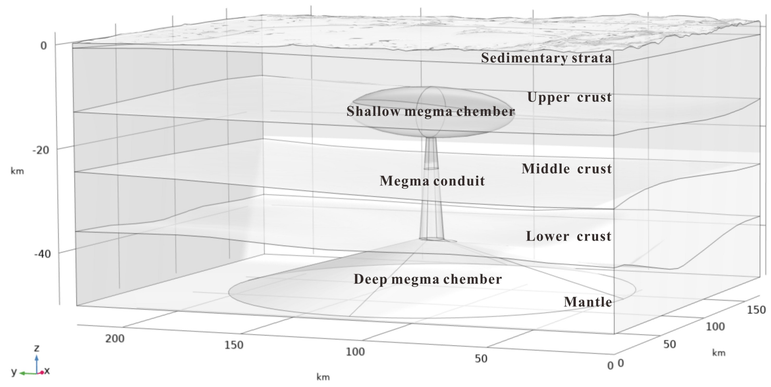


Figure 2. Three-dimensional geological model of the Changbai Mountain region (Song et al., 2025)

RESULTS

The results reveal that the surface heat flow in the Changbai Mountain region ranges from 70.1 to 130.8 mW/m², with an average heat flow of approximately 86.2 mW/m². The crust contributes a heat flow ranging from 20.8 to 33.1 mW/m², averaging about 27.7 mW/m², while the mantle contributes 48.3 to 70.1 mW/m², averaging approximately 56.7 mW/m², indicating a typical "cold crust-hot mantle" geothermal system. The thermal contribution from magma chambers shows strong regional characteristics, primarily influencing heat flow within the magma chamber distribution zones and their peripheral boundaries extending approximately 40 km. Within the magma chamber zones, their contribution to regional heat flow ranges from 53.1 to 12.3 mW/m², decreasing to 12.3–1.1 mW/m² within the 40 km boundary extension. In other areas, the thermal contribution from magma chambers is negligible (close to 0 mW/m²).

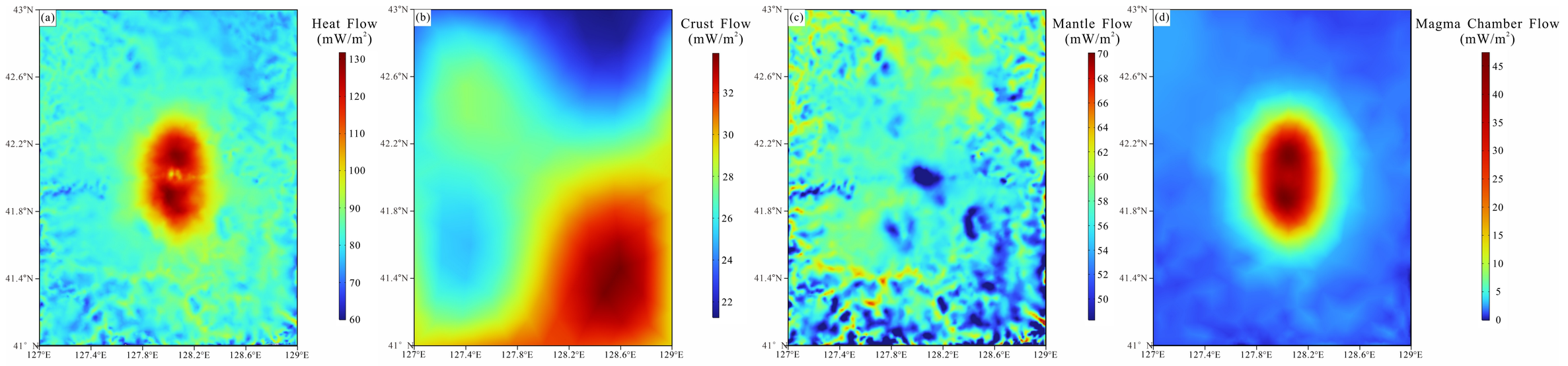


Figure 3. (a) Surface heat flow in Changbai Mountain region; (b) Crust heat flow in Changbai Mountain region; (c) Mantle heat flow in Changbai Mountain region; (d) Magma Chamber heat flow in Changbai Mountain region (Song et al., 2025)

DISCUSSION

To assess the rationality of the results, this study compares the lithospheric thermal structure of the Songliao Basin with the findings presented here. The Songliao Basin is geographically proximate to the Changbai Mountain region, and both are located above the Pacific subduction zone, sharing comparable geothermal and geological contexts. Data show that the terrestrial heat flow in the Songliao Basin ranges from 73.89 ± 14.25 mW/m², with an average mantle heat flow of 57.5 mW/m² and an average crustal heat flow of 16.4 mW/m². indicating a typical "cold crust–hot mantle" type lithospheric thermal structure (Dai et al., 2024; Chen et al., 2024). These features align closely with the results of the current study, thereby corroborating the reliability of our conclusions.

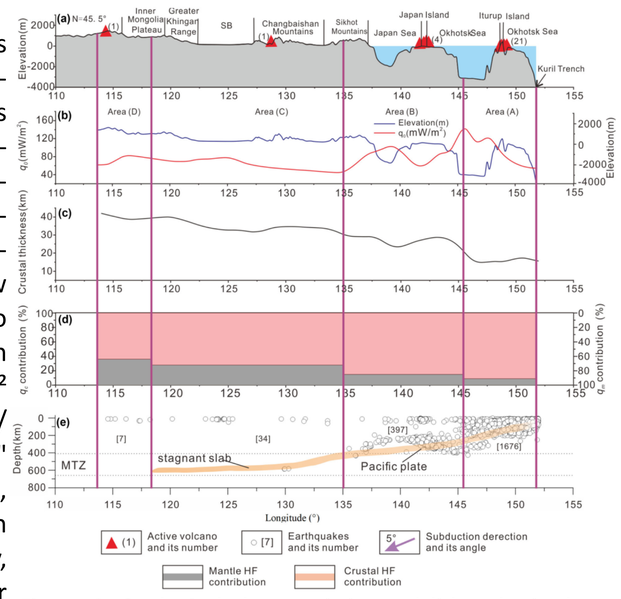


Figure 4. Geological characteristics and lithospheric thermal structure of subduction-related areas (Including Songliao Basin and Changbai Mountain) (Dai et al., 2024)

CONCLUSION

1.The surface heat flow in the Changbai Mountain region ranges from 70.1 to 130.8 mW/m², with a mean value of approximately 86.2 mW/m². The crustal contribution to the heat flow varies between 20.8 and 33.1 mW/m², averaging around 27.7 mW/m², while the mantle-derived heat flow ranges from 48.3 to 70.1 mW/m², with an average contribution of about 56.7 mW/m². The ratio of mantle heat flow to surface heat flow (q_m/q_o) exceeds 0.5, indicating a typical "cold crust–hot mantle" type geothermal system.

2.The thermal contribution of magma chambers exhibits significant regional variability, with its impact on regional heat flow primarily concentrated within the distribution areas of the magma chambers and extending approximately 40 km beyond their boundaries. Within the magma chamber distribution zones, the heat flow contribution ranges from 53.1 to 12.3 mW/m². In the peripheral region extending 40 km beyond the boundaries, the contribution decreases to between 12.3 and 1.1 mW/m². Beyond these areas, the heat flow contribution from magma chambers becomes negligible, approaching 0 mW/m².

3.The high mantle heat flow observed in the Changbai Mountain area is inferred to originate from the upwelling of asthenospheric material induced by the subduction of the Pacific Plate.

Acknowledgements

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