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ARTICLE

Geomorphometric delineation and subdivision of the Altai mountains using DEM-based analysis

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Abstract: This study redefines the borders, extent, and internal subdivisions of the Altai Mountains - one of the principal mountain systems in western Mongolia - by addressing longstanding inconsistencies in previous geographical and geological interpretations. A two-stage geomorphometric approach was applied to delineate the boundaries of the range. First, geomorphon classification was used to identify key terrain features, followed by the application of the Topographic Position Index (TPI) to refine boundary transitions based on relative elevation gradients. This combined methodology enabled the accurate differentiation of mountain extents from surrounding depressions, plains, and low-relief areas. Results indicate that the Altai Mountains extend approximately 2,400 km in a straight line from the Tigirig Range at the Russia–Kazakhstan border to the Khuut Mountain Range in Mongolia, with a cumulative watershed length of about 3,820 km. The total area covered by the range is estimated at 485,000 km2. Additionally, the study suggests that the low-relief mountain ridges in southwestern Mongolia likely represent the easternmost extension of the Tian Shan mountain system. By integrating recent neotectonic evidence with quantitative geomorphometric techniques, this research provides new insights into the structural geography of Central Asia and contributes to the refinement of regional mountain classification schemes.

Keywords: *Altai Mountains, Mongol Altai Mountains, Gobi-Altai Mountains, Gobi-Tian Shan Mountain range;*

INTRODUCTION

The Altai Mountains represent the most extensive and geologically complex mountain system in Western Mongolia and form a critical segment of the broader Altai–Sayan orogenic belt. Despite their tectonic and geomorphological significance, the range's boundaries, internal subdivisions, and total length remain inconsistently defined across the scientific literature. For example, Encyclopedia Britannica estimates that the Altai Mountains span roughly 2,000 km across Russia, Kazakhstan, Mongolia, and China, stretching from the West Siberian Plain to the Gobi Desert [1].

Similarly, UNESCO documents estimate the range at approximately 2,100 km, while other geographic sources report a total length of up to 2,525 km and a surface area of about 845,000 km^2 [2], [3], [4].

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These discrepancies underscore the lack of a standardized and reproducible approach for delineating the Altai's spatial extent and morphostructural complexity.

In Mongolia, the Altai Mountains are generally subdivided into three primary segments: the Russian Altai, Mongol Altai, and Gobi-Altai Mountains. Tavan Bogd Mountain, a prominent geographic feature located in far western Mongolia, serves as the transitional node connecting the Mongol Altai and Russian Altai ranges. Southeastward from this point, the range diverges into the Mongol Altai and Gobi-Altai chains, extending over 1,800 km into the southern regions of the country [5]. However, most existing classifications are based on generalized physiographic descriptions, lacking integration of quantitative methods or tectonic data. Seminal works by Soviet-era geographers (e.g., B.M. Sinitsin, 1959; E.M. Murzaev, 1952) proposed differing border definitions, but their conclusions were largely qualitative in nature and have not been validated through modern analytical tools.

To date, few studies have incorporated high-resolution digital elevation models (DEMs), geomorphometric indices, or geospatial analysis to systematically define the Altai Mountains' boundaries or internal structure. While morphometric analysis has gained recognition in recent decades as a reliable tool for landform classification and tectonic interpretation, its application to the Altai Mountains has remained limited. Moreover, neotectonic influences, such as recent crustal movements and fault activity, have not been fully considered in previous spatial delineations, despite their critical role in shaping the region's current topography.

This study addresses these gaps by developing a quantitative, GIS-based methodology that integrates geomorphon classification and the Topographic Position Index (TPI) to delineate both the outer boundaries and internal subdivisions of the Altai Mountains. By combining these morphometric techniques with insights from recent neotectonic research, the study introduces a reproducible and objective approach to defining the mountain range's spatial configuration. This not only enhances the scientific understanding of Central Asia's orogenic systems, but also contributes methodologically to the broader field of geomorphometric regionalization.

MATERIALS AND METHODS

To delineate the borders and subranges of the Altai Mountains, we conducted a multi-step geomorphometric analysis using digital elevation models (DEMs). This methodological framework integrates terrain classification and topographic metrics to produce a precise and reproducible delineation of mountain boundaries in western Mongolia.

Preliminary Landform Identification: Initial distinctions between major physiographic units, such as valleys, depressions, and low-lying plains, were identified through visual interpretation and elevation profiling. These features served as primary indicators separating mountainous terrain from surrounding lowlands.

Geomorphon Classification: To generate a detailed landform map, we applied the geomorphon classification method, a pattern-recognition-based approach that uses relative elevation differences to categorize each cell in a DEM. This technique allows the classification of terrain into ten primary landform types: flat (FL), peak (PK), ridge (RI), shoulder (SH), spur (SP), slope (SL), hollow (HL), footslope (FS), valley (VL), and pit (PT) [6], [7], [8]. Geomorphons function as both terrain attributes and landform categories, significantly simplifying the task of landform mapping by producing label-based classifications across large areas.

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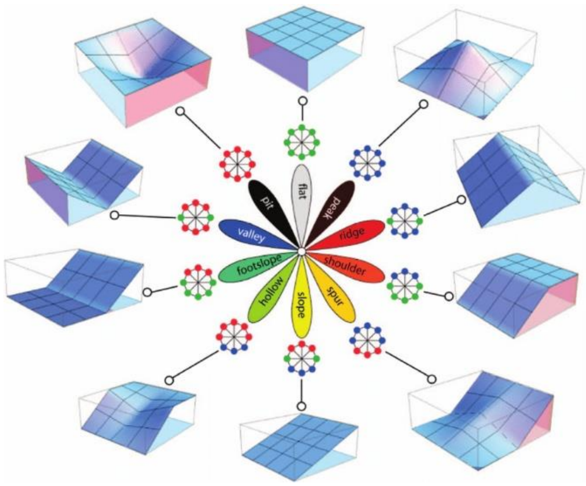

−\+	0	1	2	3	4	5	6	7	8
0	FL	FL	FL	FS	FS	VL	VL	VL	PT
1	FL	FL	FS	FS	FS	VL	VL	VL	_
2	FL	SH	SL	SL	HL	HL	VL	_	_
3	SH	SH	SL	SL	SL	HL	_	_	_
4	SH	SH	SP	SL	SL	_	_	_	_
5	RI	RI	SP	SP	_	_	_	_	_
6	RI	RI	RI	_	_	_	_	_	_
7	RI	RI	_	_	_	_	_	_	_
8	PK	_	_	_	_	_	_	_	_

Figure 1. Forms represented by geomorphons (geomorphons into the 10 common landform types. FL - flat; PK - peak; RI - ridge; SH - shoulder; HL - hollow; SL - slope; SP - spur; FS -footslope; VL - valley; PT – pit) by Stepinski (2011).

The geomorphon method analyzes the elevation profile surrounding each DEM cell within a predefined search radius and compares the central cell's elevation with those along multiple radial directions. By evaluating these relative elevation differences and their spatial patterns, the method identifies distinct terrain forms that correspond to specific landform categories. This automated classification reduces subjective bias and enhances reproducibility in geomorphological mapping.

Topographic Position Index (TPI) Analysis: The Topographic Position Index was used to further refine the classification of landforms and identify elevation transitions. TPI compares the elevation of a central cell to the mean elevation of surrounding cells within a defined neighborhood. It is calculated as:

$$TPI_i = M_0 - \sum_{n-1} M_n / n \qquad (1)$$

where M_0 is the elevation of the model point under evaluation, M_n is the elevation of grid, and n represents the total number of surrounding points employed in the evaluation [9], [10], [11]. TPI quantifies the relative position of a location in the landscape by measuring how much higher or lower the central point is compared to its surroundings.

Positive TPI values indicate that the location is elevated relative to its neighborhood (e.g., ridges or peaks), whereas negative values indicate depressions, such as valleys or basins. Values near zero typically correspond to flat or gently sloping areas. The scale of analysis (neighborhood size) strongly influences the type of features detected, making TPI a flexible tool for multi-scale terrain characterization.

TPI aids in identifying terrain features such as valley bottoms, flat surfaces, constant slopes, ridgelines, and localized peaks. However, this method is scale-dependent: the radius of the surrounding window significantly affects terrain classification accuracy. Larger-scale settings can identify broad terrain features, such as valleys and watersheds, while smaller-scale settings are more sensitive to local variations like hills or terraces.

Integration and Border Delineation: The final delineation of mountain borders was derived by integrating geomorphon and TPI outputs. Zones of transition between negative (depressions, flatlands) and positive (ridges, peaks) landforms, particularly, where multiple

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classification types intersect, were used to draw natural boundaries. This integration allowed for the systematic and objective identification of the extent of the Altai Mountains and their sub-ranges.

RESULTS AND DISCUSSION

The Altai Mountains

The borders of the Altai Mountains system were identified based on transitions in geomorphon landform classifications, specifically where slopes (SL) change to flat (FL) and depression (PT) landforms, as well as by the intersection of transition lines from negative to positive landforms as defined by the Topographic Position Index (TPI). The alignment of these positive-to-negative transitions with specific contour lines improves the precision of the boundary determination, thereby enhancing the value of this research.

The Altai Mountains begin at the southern foothills of the Aj Bogd Mountain range, separated from surrounding lowlands by an approximate elevation of 1,000 meters above sea level, near the depressions of Nomin Gobi and Zuun Gobi, which span the territories of China, Kazakhstan, and Russia. Additionally, a continuous border line at around 600 meters separates the Altai Mountains from the Erchis River basin and the Western Siberian Plain.

The borders of the Altai Mountains were delineated based on transitions observed in geomorphon landform classifications, particularly where slopes (SL) transition into flat (FL) and depression (PT) landforms. This was complemented by the Topographic Position Index (TPI), which identified shifts from negative to positive landform values. The congruence of these transitions with specific contour lines enhanced the precision of boundary determination, thereby, strengthening the reliability of this study.

The Altai Mountains originate from the southern foothills of the Aj Bogd Mountain range, separated from adjacent lowlands by an elevation threshold of approximately 1,000 meters near the Nomin Gobi and Zuun Gobi depressions, which span parts of China, Kazakhstan, and Russia. Additionally, a continuous boundary at roughly 600 meters above sea level separates the Altai Mountains from the Erchis River basin and the Western Siberian Plain.

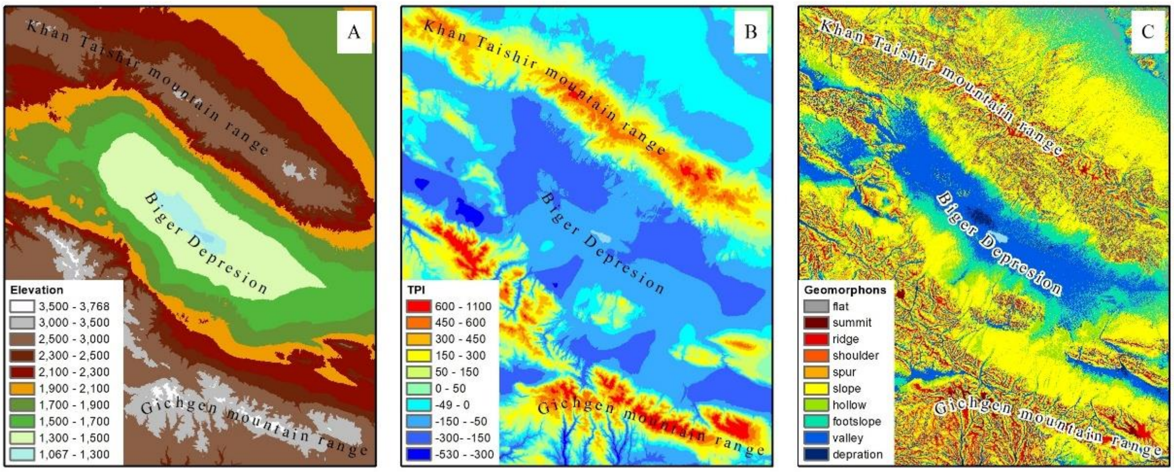

Figure 2. A-Elevation, B-Topographic position index, C-Geomorphons.

Within Mongolia, the Altai Mountains are bounded by lines that vary depending on regional surface elevation. For instance, the border with adjacent lowlands is approximately 1,300 meters above sea level in the Great Lakes Depression, 1,500 meters in the Valley of the Lakes, and 1,300 meters in the valleys of Altai Uvur Gobi and Nomin Gobi. These variations highlight the influence of relative elevation across different regions in Mongolia.

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The Altai Mountains, Western Sayan Mountains, and the Tagna mountains constitute a single-folded mountain system. Although these ranges are not separated by prominent valleys, depressions, or plains, they are called by distinct names due to their geographical formations extending along the latitude and longitude. The mountain folds of the Altai, Western Sayan, and Tagna mountain ranges encompass an area of approximately 620,000 km^2. However, this study specifically sought to define the Altai Mountains independently, recognizing their unique geographical features that extend predominantly along latitude and longitude.

The Altai Mountains were distinguished from the Western Sayan and Tagna Mountains by major faults lines, including the Chulyshman River Valley, the source of the Ob River in Russia, and the faults traversing the Kharig River Valley and Uureg Lake depression in Mongolia. Based on these criteria, the Altai Mountains were estimated to cover an area of approximately 485,000 km² when considered as a distinct unit.

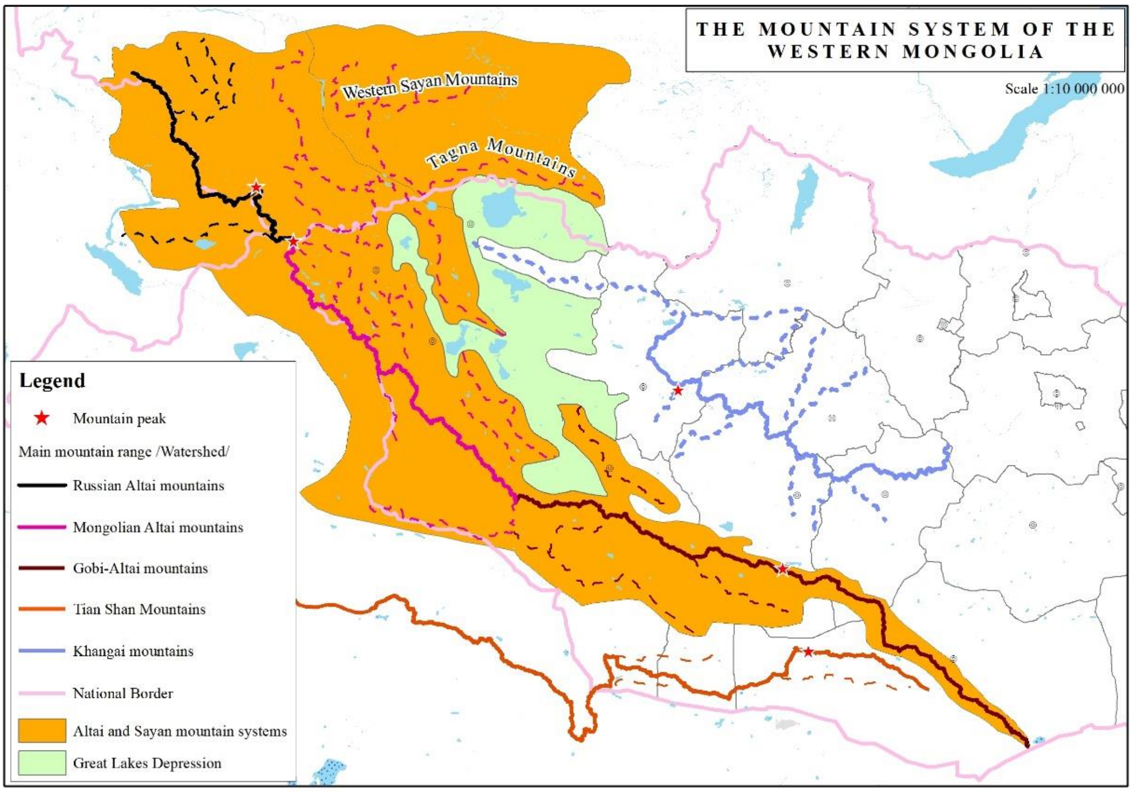

Figure 3. The mountain system of Western Mongolia.

The Altai Mountains range extends from northwest to southeast, spanning the borders of Russia, Kazakhstan, Mongolia, and China. The recorded length of the Altai Mountains range varies across literatures. Beginning in the northwest at the Tigirig Range and the Tigirigsky Nature Reserve along the Russian-Kazakh border, the Altai range follows the borders of Russia and Kazakhstan, then Russia and China, primarily aligned along the watershed of the Altai. The range continues southeastward to Altai Tavan Bogd in Western Mongolia. From the Tigirig Range to Altai Tavan Bogd, the Altai Mountains range cover a length of approximately 570 km, with the precise watershed extending around 740 km. Beyond this point, the Altai range stretches for an additional 1,800 km along the Mongolia-China border, reaching toward the Khurkh and Khuut Mountain Ranges, which represent extensions of the Gobi-Altai sub-range. Consequently, the Altai Mountains cover approximately 2,400 km from beginning to end, with the cumulative watershed totaling around 3,820 km.

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Drainage areas within the Altai Mountains Range across Mongolia, Kazakhstan, Russia and China were delineated using Hydrology tools within the Spatial Analyst extension of ArcGIS software. Analysis indicates that the Altai Mountains belongs to both the Central Asian Internal Drainage basin and the Erchis River basin, extending from the Tigirig mountain Range to the Khuut Mountain Range. Additionally, the Altai Range serves as a natural divide, separating the basins of the Ongi, Tui, Taats, and Khyargas-Zavkhan Rivers, originating from the Khangai Mountains Range, from those of the Uench-Bodonch River and Upper Gobi Basin.

The Mongol Altai Mountains

Recent neotectonic studies substantiate the definitions proposed by V.M. Sinitsin (1959) and S.Jigj (1975), which designate the Alag Lake depression as the border between the Mongol Altai and Gobi-Altai Mountains ranges. Thus, the Mongol Altai Mountains range is considered to span over 800 km, from Altai Tavan Bogd to the Zuulun Bogd Pass (close to the Alag Lake Depression), between the Alag Khairkhan Mountain and the Aj Bogd Mountains. Alternative perspectives suggest that the Mongol Altai Mountains range terminates at the Gichgene Mountain range, with the main ridge of the Altai continuing uninterrupted from Altai Tavan Bogd to Gichgene. At this point, the Mongol Altai is believed to diverge as subtle valleys and channels separate the ridges. Despite this interpretation, geological, tectonic, and neotectonic studies strongly contest the idea that these separated ridges represent the true termination of the range. Although valleys begin to divide the main ridges near the Bayantsagaan range, detailed watershed estimations - from the Tigirig range in the northwestern Altai to the southeastern Khurkh and Khuut Mountains ranges - demonstrate a continuous stretch of approximately 3,280 km, contradicting the view that the range terminates at the Gichgene Mountain range.

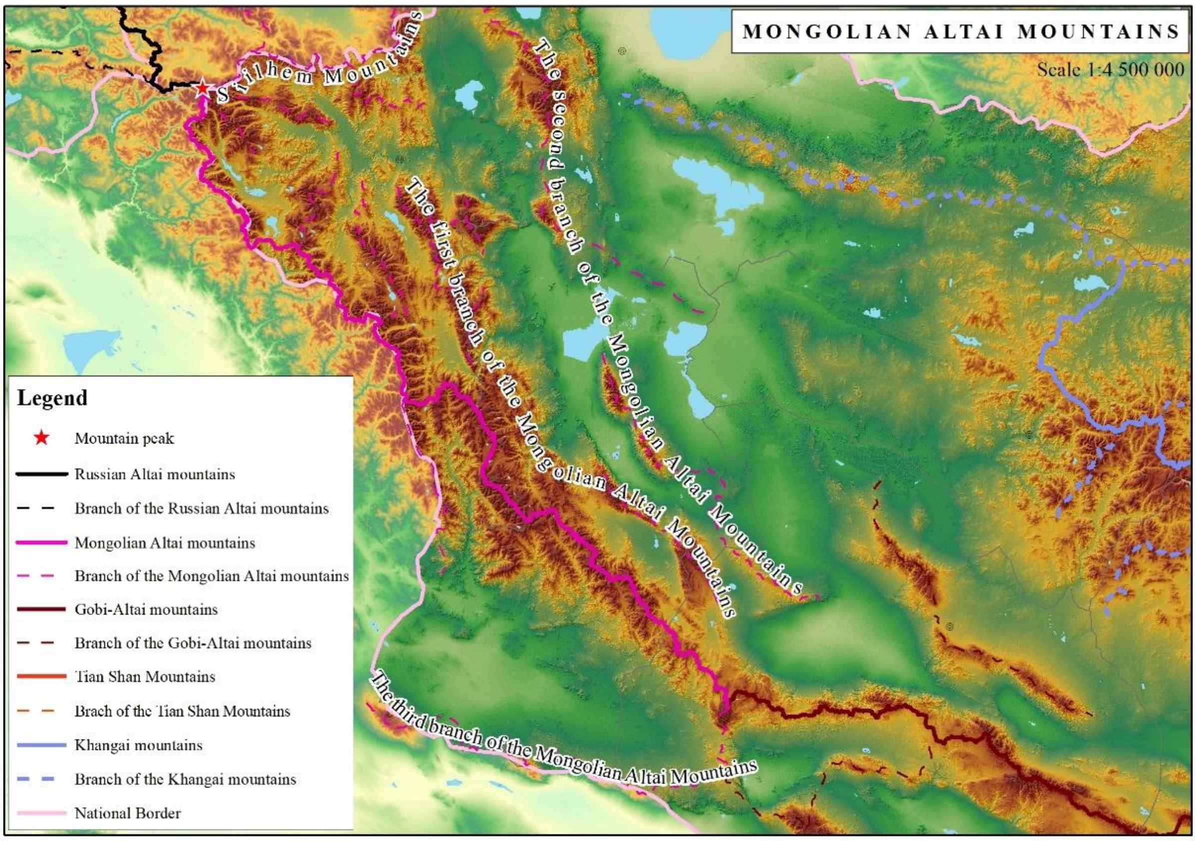

Figure 4. Mongol Altai Mountains.

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Some researchers have distinguished the Mongol Altai and Gobi-Altai Mountain ranges based on landscape differences; however, this approach is limited at some level. The landscape variations primarily reflect differences in soil and vegetation, which arise from the distinct climatic zones across latitudes rather than inherent mountain structure. While the Mongol Altai and Gobi-Altai Mountains are commonly categorized separately, they are, in fact, part of a single folded mountain range - the Altai Mountain range - that shares a common origin and formation period. Their division is based primarily on subtle differences in landform, structural features, and recent neotectonic movements. Moreover, the names and divisions of these mountain ranges have influenced administrative units in Mongolia, leading to the naming of Gobi-Altai aimag. If it is assumed that the Mongol Altai Mountains terminates at the Gichgene Mountain range and that the Gobi-Altai Mountains begins at the Bayantsagaan Mountain range, it would imply that the Gobi-Altai range actually commences within the borders of Bayankhongor aimag, which does not correspond to the territory of today's Govi-Altai aimag.

The Gobi-Altai Mountains

The Gobi-Altai Mountain Range is thought to originate at the intersection of two prominent strike-slip fault systems. These include the right-lateral strike-slip faults of the Mongol Altai Mountains, which extend from northwest to southeast, and the left-lateral strike-slip fault that intersect the Mongol Altai fault system from east to west. Consequently, the Gobi-Altai Mountain Range is believed to span over 1,000 km, stretching from the Khan Jargalant Mountain Range and the Khar Azarga Mountain Range, which mark the front side of the Sharga depression to the far reaches of the Khurkh and Khuut Ranges.

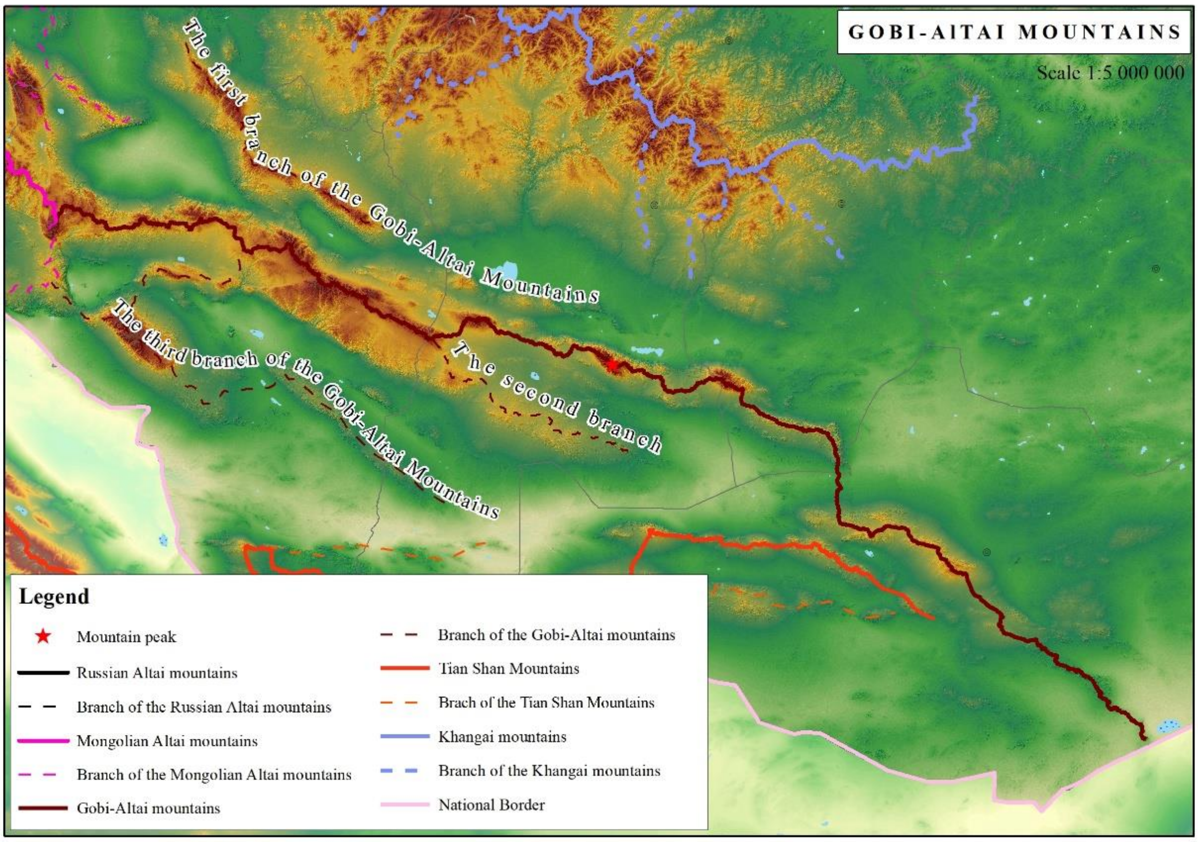

Figure 5. Gobi-Altai Mountains.

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Some researchers regard the Altai Uvur Gobi Mountains as a third range within the broader Gobi-Altai Mountain range. For instance, S. Jigj (1975) considered that the mountains such as Bayan-Undur, Nemegt, Sevrei, Nomgon, Chingis and Tsagaan Bogd belong to the third range, though contrasting perspectives exist among scholars. The Gobi-Altai Mountain range is divided into northeastern and southeastern parts by a significant depression known as the Nemegtein Ar Strait.

The Tian Shan Mountains

The Tian Shan Mountain range runs along Mongolia's southwestern border and consists of ridges separated by flat plains, with elevations ranging from 2,000 to 2,800 meters above sea level. This range is distinct from the Altai Mountains, with separation defined by the valleys and straits of Nomin Gobi, Khar Sair Valley, Nariin Khukh Strait, Ingen Khuuvur Strait, and Nemegtein Ar Strait, as well as by the left-lateral Gobi-Tian Shan fault system, the longest fault system in Central Asia.

The Tian Shan Mountain Range comprises of two parallel rows of ridges that begin in the southwestern foothills of Khalkh, extending through Atas Bogd Mountain and reaching the Zuulun Mountain Range. This formation continues toward the center of the region, culminating in the Gurvan Saikhan Mountain range of the Gobi-Altai Mountain Range.

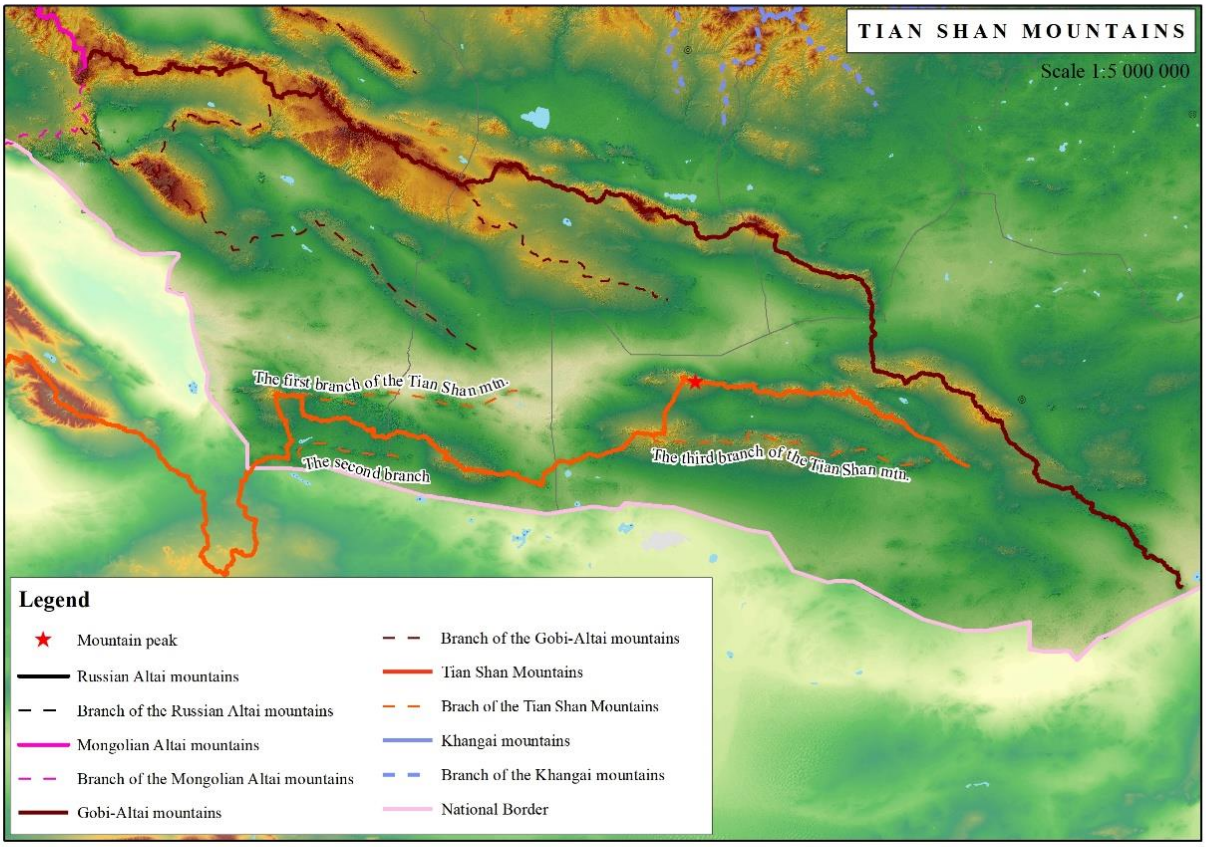

Figure 6. Tian Shan Mountains.

The Altai Mountains were formed during the great orogenic upthrusts occurring between 500 and 300 million years ago and were worn down into a peneplain over geologic time [1], [12]. The Mongol Altai and the Gobi-Altai Mountains, characterized by elevations of 3,000–3,300 meters and flat-topped summits, represent uplifted surfaces of ancient plains, as revealed by recent thermochronology studies. These studies indicate that these surfaces, formed during the Jurassic period and preserved for approximately 150 million years, remained unaffected by tectonic activities until the

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most recent compression event, which occurred around 5±3 million years ago [13]. The current relief of the Mongol Altai and Gobi-Altai Mountains began to develop around this time, largely as a result of the Indo-Asian collision, which took place roughly 2,000 km to the south during the Cenozoic era [14]. The geomorphology of Mongolia is also significantly influenced by the interactions between the Chinese and Siberian platforms, which have played crucial roles in shaping both the regional landscape and the formation of the continental crust. Additionally, the Indian microcontinent continues to exert pressure on the Eurasian plate, advancing at a rate of approximately 5 cm per year, making it a dominant force in ongoing neotectonic movements in Mongolia. The timing of mountain formation in Central Asia postdates that of the Himalayas due to the gradual dissipation of deformation forces from the Indian-Eurasian plate collision further inland. Neotectonic research indicates that the formation of major mountain ranges occurred sequentially: the Himalayan range formed around 55 million years ago, followed by the Kunlun Shan and Qilian Shan 40-30 million years ago, the Tian Shan 15-10 million years ago, the Altai 8-2 million years ago, and, finally, the Western Sayan Mountain range approximately 1 million years ago [15].

The Altai Mountains in Mongolia, an extension of the larger Altai range, are generally divided into the Mongol Altai and Gobi-Altai Mountains. A border of these divisions, however, vary across studies. The Mongol Altai Mountains gradually diminishes in elevation from northwest to southeast, fragmenting into multiple ridges. Notably, B. M. Sinitsin (1959) defined the Mongol Altai as stretching approximately 800 km, terminating near the Alag Lake depression, whereas E. M. Murzaev (1952) proposed a broader border extending up to 1,000 km to the Gichgene Mountain range, which he considered the eastern limit of the Mongol Altai Mountains. The arid conditions of the Gobi region complicate the precise demarcation of the Mongol Altai's southeastern border, particularly as the ridges start to diverge near the Gichgene Mountain range, making it challenging to determine the primary ridge. Consequently, the Gichgene Mountain range is commonly recognized as the easternmost extent of the Mongol Altai Mountains [5]. Geological and tectonic evidences suggest that the Mongol Altai system ends around the depressions of Alag Lake and Shargiin Tsagaan Lake [16]. Considering the diverse origins, structures, and fault directions of the Mongol Altai and Gobi-Altai Mountains, these two ranges are not tectonically continuous [17], [18]. Observations reveal that the displacement in the central Altai and eastern Gobi-Altai regions occurs at an angle of 340° at a rate of approximately 5.2 mm per year. In the Mongol Altai, the central crust shifts WNW at 354° at a rate of 4.8 mm per year, while the Gobi-Altai moves at 91° at a rate of 1.2 mm per year. These movements result in counterclockwise rotation of the Mongol Altai and clockwise rotation of the Gobi-Altai Mountains range [15]. Beginning from the Sharga Basin, considered the border between these ranges, the region is characterized by right-lateral faults in the Mongol Altai and left-lateral faults in the Gobi-Altai, extending from northwest to southeast [13], [15].

V. M. Sinitsin (1959) proposed that sub-ranges of the Tian-Shan Mountains extend into the southeastern Gobi-Altai Mountains range, suggesting an eastward alignment for certain mountain segments in this region. In contrast, E. M. Murzaev (1952) contended that the Nemegt, Sevrei, and Nomgon mountains, positioned in the eastern front row, differ from the Gurvan Saikhan Mountain range based on their orientation and positioning; thus, he assigned these mountains to the Tian Shan system, rather than the Altai system [5]. The mountain ranges running from west to east across the Altai Uvur Gobi mountains are separated from the Gobi-Altai Mountains range by expansive valleys and straits, including Nomin Gobi, Khar Sair Valley, Nariin Khökh Strait, Ingen Khuuvur Strait, and Nemegtein Ar Strait. At the southern edge of these valleys, the Gobi-Tian Shan fault system, an extension of the Tian Shan range, stretches through the restraining bends of the Barkol Tagh and Bogda Shan ranges for over 1,200 km, crossing behind the Altan and Nemegt mountains along the left-lateral strike-slip fault of Central Asia and reaching the Gurvan Saikhan Mountain range of the Gobi-Altai Mountain Range [13], [19], [20], [21]. Accordingly, this study considers the mountains east of the Zuulun Mountain Range, spanning from the Atas and Inges Mountains, as sub-ranges of the Tian Shan Mountains.

CONCLUSIONS

This study redefines the borders, extent, naming, and internal divisions of the Altai Mountains by integrating morphometric classification methods and recent neotectonic research.

Our results indicate that the Altai Mountains extend approximately 2,400 km from the Tigirig Mountain Range on the Russia-Kazakhstan border to the Khuut Mountain Range in Mongolia, with a watershed length of about 3,820 km. Although the Altai, Tagna, and Sayan Mountains form a continuous folded mountain system, the Altai Mountains are distinguished as an independent unit based on major fault lines such as the Chulyshman River Valley and faults near the Kharig River Valley and Uureg Lake depression. The Altai Mountains cover an estimated area of approximately 485,000 km^2.

This study clarifIes key issues regarding the classification and boundaries of Western Mongolia's mountain systems, particularly resolving inconsistencies in previous definitions between the Mongol Altai and Gobi-Altai subranges. These findings contribute to a more precise understanding of Central Asia's orogenic structures and provide a solid foundation for future geological and geographical investigations.

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Ethical approval

Not applicable. This study did not involve human participants or animals, and therefore, did not require ethical approval.

Author contribution

B. B. and P. M. contributed to the study design, idea generation, analysis, and conceptualization. B. B., P. M., and O. E. prepared spatial data for processing and interpreting the results. B. B. wrote the original draft. P. M. and O. E. contributed to writing the results and discussion and providing advice. All authors reviewed the results and approved the final version of the article.

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Conflict of interest

The authors declare that there is no conflict of interest.

REFERENCES

1. "Encyclopedia Britannica | Britannica." Accessed: May 13, 2024. [Online]. Available: https://www.britannica.com/.
2. U. W. H. Centre, "UNESCO World Heritage Centre," UNESCO World Heritage Centre. Accessed: May 13, 2024. [Online]. Available: https://whc.unesco.org.
3. McColl, R. W. Encyclopedia of World Geography. Infobase Publishing, 2014.
4. "Wikipedia, the free encyclopedia." Accessed: May 13, 2024. [Online]. Available: https://www.wikipedia.org/.
5. Tsegmid, Sh. Physical Geography of Mongolia. Ulaanbaatar: Institute of Geography, Mongolian Academy of Sciences, 1969.
6. "GIS Mapping Software, Location Intelligence & Spatial Analytics | Esri." Accessed: May 13, 2024. [Online]. Available: https://www.esri.com/en-us/home.
7. Jasiewicz, J., Stepinski, T. F. Geomorphons – a pattern recognition approach to classification and mapping of landforms, Geomorphology, vol. 182, pp. 147–156, Jan. 2013, https://doi.org/10.1016/j.geomorph.2012.11.005.
8. Stepinski, T. F., Jasiewicz, J. Geomorphons-a new approach to classification of landforms. Proceedings of geomorphometry, 2011.
9. Enkhjargal, O., Bumtsend, B., Tovuudorj, R. Landform classification based on topographic position Index: (A case study in Ulaanbaatar city), Mong. J. Geogr. Geoecology, pp. 218–226, Dec. 2022, https://doi.org/10.5564/mjgg.v59i43.2530.
10. Vinod, P. G. Development of topographic position index based on Jenness algorithm for precision agriculture at Kerala, India, Spat. Inf. Res., vol. 25, no. 3, pp. 381–388, Jun. 2017, https://doi.org/10.1007/s41324-017-0104-8.
11. Jenness, J. Topographic position index (tpi_jen.avx_extension for Arcview 3.x, v.1.3a, Jenness Enterprises [EB/OL], http://www.jennessent.com/arcview/tpi.htm, 2006, Accessed: Oct. 02, 2024. [Online]. Available: https://cir.nii.ac.jp/crid/1571980075747932288.
12. Cai, K., et al. Crustal nature and origin of the Russian Altai: Implications for the continental evolution and growth of the Central Asian Orogenic Belt (CAOB), Tectonophysics, vol. 674, pp. 182–194, Apr. 2016, https://doi.org/10.1016/j.tecto.2016.02.026.
13. Cunningham, D. Owen, L.A., Snee, L.W., Jiliang, L. Structural framework of a major intracontinental orogenic termination zone: the easternmost Tien Shan, China, J. Geol. Soc., vol. 160, no. 4, pp. 575–590, Jul. 2003, https://doi.org/10.1144/0016-764902-122.
14. Cunningham, W. D. Lithospheric controls on late Cenozoic construction of The Mongol Altai, Tectonics, vol. 17, no. 6, pp. 891–902, 1998, https://doi.org/10.1029/1998tc900001.
15. Bayasgalan, A., Khishigsuren, S. Neotectonic movement of Mongolia, Geol.Issues, vol. 10, pp. 80-95, 2009.
16. Jigj, S. The main features of the depressions in Mongolia. Ulaanbaatar, 1975.
17. Byamba, J. Geographical Overview of the Territory of Mongolia (On the Issue of Physical-Geographical Zoning), Geol. Issues, vol. 4, pp. 279–300, 2001.
18. Timofeev, D., Nikolaeva, T. The Gobi Altai and the Trans-Altai Gobi, in Geomorphology of the Mongolian People's Republic, Moscow, p. 65, 1982.
19. Cunningham, W. D., Windley, B. F., Dorjnamjaa, D., Badamgarov, J., Saandar, M. Late Cenozoic transpression in southwestern Mongolia and the Gobi

Altai-Tien Shan connection, Earth Planet. Sci. Lett., vol. 140, no. 1, pp. 67–81, May 1996, https://doi.org/10.1016/0012-821x(96)00048-9.

20. Owen, L. A., Cunningham, W. D., Windley, B. F., Badamgarov, J., & Dorjnamjaa, D. The landscape evolution of Nemegt Uul: a late Cenozoic transpressional uplift in the Gobi Altai, southern Mongolia," Geological Society, London, Special Publications, vol. 162. Jan. 01, 1999. https://doi.org/10.1144/GSL.SP.1999.162.01.

21. Rippington, S. The Crustal Evolution of Nemegt and Altan Uul, Southern Mongolia, Jan. 2008.