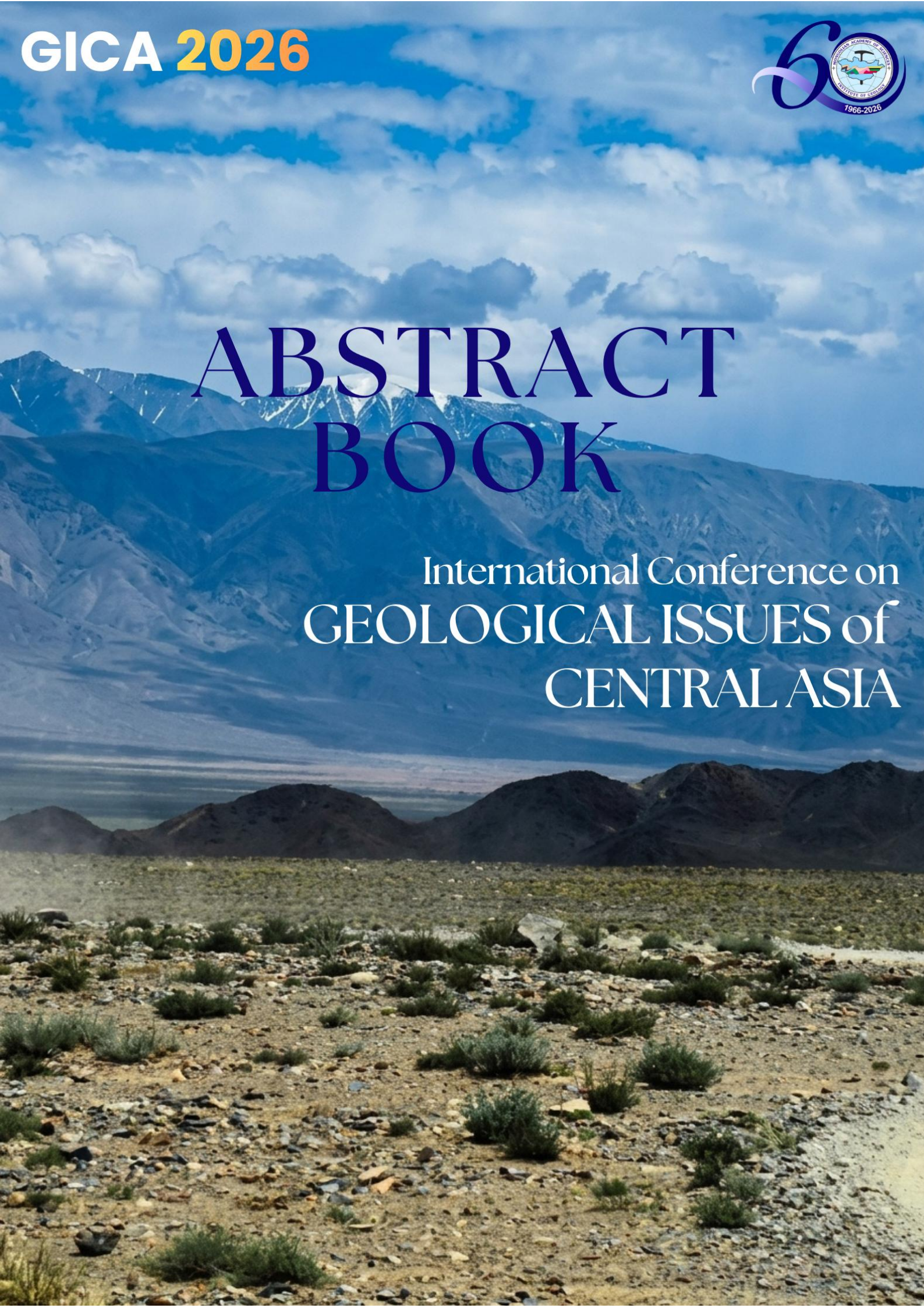
GICA 2026



ABSTRACT BOOK

International Conference on GEOLOGICAL ISSUES of CENTRAL ASIA

MONGOLIAN ACADEMY OF SCIENCES
INSTITUTE OF GEOLOGY

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Ulaanbaatar, 2026

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FOREWORD

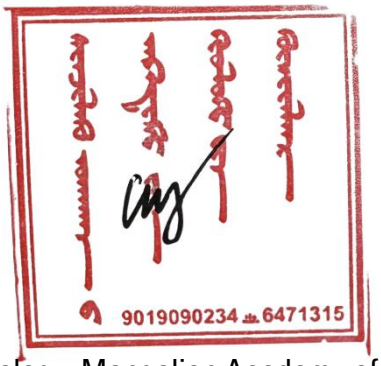
The Geological Issues of Central Asia 2026 (GICA 2026) is an international platform for geoscientists focused on the tectonic evolution, mineral resources, and paleoenvironments of Central Asia.
Initiated by the Institute of Geology at the Mongolian Academy of Sciences, the meeting is made possible through collaboration with our esteemed domestic and global partners:

- Domestic Co-Organizers: Mongolian University of Science and Technology, National University of Mongolia, and Erdenet Mining Corporation.
- International Partners: Czech Geological Survey, Polish Geological Institute – National Research Institute, Charles University Prague, Institute of Geology and Geophysics of the Chinese Academy of Sciences, China University of Geosciences (Beijing), Institute of the Earth's Crust SB RAS, A. P. Karpinsky All-Russian Geological Research Institute, University of Utah, University of Vermont, and Curtin University.

The conference is generously powered by Rio Tinto Mongolia and supported by the National Science and Technology Fund of Mongolia.
This year's event proudly coincides with the 60th anniversary of the Institute of Geology, founded in 1966. Over the past six decades, the Institute has evolved into Mongolia's principal national center for fundamental geological research. To mark this milestone, we have expanded our international programming, featuring GICA 2026 as its centerpiece.
We extend our deepest gratitude to our sponsors, co-organizers, and the colleagues joining us in Ulaanbaatar from Mongolia, Czechia, Poland, China, the Russian Federation, Japan, the United States, and Australia.

On behalf of the Organizing Committee, we look forward to welcoming you this September.

Dr. Turbold Sukhbaatar



Director, Institute of Geology, Mongolian Academy of Sciences
Chair, GICA 2026 Organizing Committee

TOPICS

I. PALEOGEOGRAPHY OFTHE CENTRAL ASIAN OROGENIC BELT AND SUPERCONTINENT CYCLE

II. MONGOLIAN COLLAGE ANDTECTONICS

III. BASIN ANALYSIS AND STRATIGRAPHY

IV. ISOTOPE GEOCHEMISTRY, GEOCHRONOLOGY, CRUSTAL EVOLUTION

V. MINREAL RESOURCES AND METALLOGENY

VI. ADVANCEDTEHCNOLOGY AND DATA ANALYSIS

ORGANIZING COMMITTEE

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	Prof. Laura Webb	Prof. Inna Safonova
	Prof.Yuan Gao	Prof.Yingde Jiang
	Dr. Rafal Sikora	

CONFERENCE SESSION

DAY 1, WEDNESDAY, 16 SEPTEMBER 2026

10:00 **Opening speech**

SESSION I

Paleogeography of the Central Asian Orogenic Belt and Supercontinent Cycle

Chairman: **Dr. Turbold Sukhbaatar, Prof. Inna Safonova**

10:30 Keynote: **Prof. Karel Schulmann**
The Ediacaran–Cambrian assembly of Siberomongolia: processes and mechanisms of continental construction *Czech Geological Survey, **Czechia***

10:50 Keynote: **Dr. Dmitry P. Gladkochub**
The southern Siberian craton in the Neoproterozoic: from the breakup of Rodinia to the origin of the Central Asian Orogenic Belt: geodynamics and mineral resources
*Institute of the Earth's Crust SB RAS, Irkutsk, **Russia***

11:10 Keynote: **Prof. Wenjiao Xiao**
Making of the Central Asian Orogenic Belt: Insights into the Archean tectonics
*Institute of Geology and Geophysics, CAS, **China***

11:30 Keynote: **Prof. Inna Safonova**
Subduction erosion at Pacific-type convergent margins: a review and examples from the Central Asian Orogenic Belt
*Southwest Jiaotong University, China; Novosibirsk State University, **Russia***

11:50 Keynote: **Dr. Igor Soejono**
Cryptic basement as the clue to unraveling orogenic configuration: Case studies from the Variscan and Central Asian orogenic belts
*Czech Geological Survey, **Czechia***

12:10 Keynote: **Dr. Tatiana V. Donskaya**
Ediacaran Accretionary Events in the Northern Central Asian Orogenic Belt
*Institute of the Earth's Crust SB RAS, Irkutsk, **Russia***

12:30 **Lunch**

SESSION II

Mongolian Collage and Tectonics

Chairman: **Prof. Karel Schulmann, Prof. Tatiana V.Donskaya**

13:20 Keynote: **Dr. Turbold Sukhbaatar**
Establishing the Continental Core: an analysis of terrane transitions in the Mongolian collage
*Institute of Geology, MAS, **Mongolia***

13:40 Keynote: **Prof. Gerel Ochir**
Petrogenesis and metallogenic implications of Li–F granites in Mongolia: constraints from geochemistry, mineral chemistry and geochronology
*Geoscience Center, Mongolian University of Science and Technology, **Mongolia***

14:00 Keynote: **Prof. Laura Webb**
Records of polyphase orogenesis and the transition to intraplate deformation in southeastern Mongolia
*University of Vermont, **USA***

14:20 Keynote: **Dr. Sanchir Dorjgochoo**
Ophiolites in Mongolia: Implications for the Spatiotemporal and Tectonic Evolution of the CAOB
Institute of Geology, MAS, ***Mongolia***

14:40 Keynote: **Prof. Yingde Jiang**
From Chaotic Accretion to Ordered Cratonization: The Altai Story Told by Deformation–Metamorphism–Magmatism
Guangzhou Institute of Geochemistry, CAS, ***China***

15:00 **Coffee break**

15:15 Keynote: **Prof. Li Pengfei**
Oroclines in the Central Asian Orogenic Belt: A Tale of Deep Processes and Surface Response
Guangzhou Institute of Geochemistry, CAS, ***China***

15:35 Keynote: **Prof. Zhao Pan**
Evolution of the Mongol-Okhotsk Ocean: Constraints from paleomagnetism
Institute of Geology and Geophysics, CAS, ***China***

15:55 Keynote: **Dr. Alexandra Guy**
Architecture of the Mongolian Orocline and its geodynamic evolution
Czech Geological Survey, Prague, ***Czechia***

16:15 **Dr. Elena Demonterova**
The Hangai Dome in central Mongolia: A geophysical and geochemical perspective on the origin of intraplate basaltic volcanism
Institute of the Earth's Crust SB RAS, ***Russia***

16:30 **Prof. Susana Henriquez** (Virtual)
Using zircon (U-Th)/He thermochronometry to investigate the growth and collapse of the Mongol-Okhotsk Orogenic Belt
California State University San Bernardino, ***USA***

16:45 **Dr. Justin Tully** (Virtual)
Extra-prolate metamorphic core complexes of the Mongol-Okhotsk orogenic belt: Insights from Ereendavaa & Buteel
University of Utah, UT, ***USA***

DAY 2, THURSDAY, 17 SEPTEMBER 2026

SESSION III

Basin Analysis and Stratigraphy

Chairman: **Prof. Yingde Jiang, Assoc. Prof. Undariya Jalbaa**

09:00 Keynote: **Prof. Yuan Gao**
International Continental Scientific Drilling Project of the Songliao Basin: Terrestrial Geological Records of the Cretaceous Dinosaur Age
State Key Laboratory of Geomicrobiology and Environmental Changes, China University of Geosciences, ***China***

09:20 Keynote: **Prof. Ulambadrakh Khukhuudei**
Cenozoic regional tectonics of Mongolia
National University of Mongolia, ***Mongolia***

09:40 **Dr. Rafał Sikora**
Tsakhiurtyn Hundi Lakeland and Khutul Usny Cave – geology, paleoenvironment, and early Homo sapiens (Arts Bogd, Mongolia)
Polish Geological Institute – NRI, ***Poland***

09:55 **Dr. Badamkhatan Zorigt**
Recent advances in Mongolian vertebrate paleontology and their implications for Cretaceous stratigraphy
Institute of Paleontology, MAS, ***Mongolia***

10:10 **Dr. Christian Leipe**
Hydroclimatic variability in northern Inner Asia over the past 2500 years inferred from varved sediments of Lake Shira (Chulym-Yenisei Basin, southern Siberia)
Freie Universität Berlin, ***Germany***

10:25 **Dr. Paul Rummy**
The Rise of Paralligatorids: Evolutionary Radiation Across Cretaceous Asia
Institute of Vertebrate Paleontology and Paleoanthropology, CAS, ***China***

10:40 **Coffee break**

SESSION IV

Isotope Geochemistry, Geochronology, Crustal Evolution

Chairman: **Prof. Laura Webb, Dr. Uyangaa Udaanjargal**

11:00 Keynote: **Prof. Chris Clark**
Developing petrologically informed geodynamic models
Curtin University, ***Australia***

11:20 **Assoc. Prof Pavla Štípská**
Zircon melt-mediated coupled dissolution-precipitation and the effect on calculated ages: an overlooked mechanism of zircon modification, implications for CAOB
Czech Geological Survey, ***Czechia***

11:35 **Dr. Baigalimaa Ganbat**
Upper mantle structure and the Amurian plate boundary beneath Mongolia from Surface wave tomography
Institute of Astronomy and Geophysics, MAS, ***Mongolia***

11:50 **Dr. Arnaud Broussolle** (Virtual)
Tracing the evolution of the supercontinent cycle through Hf isotopes in the Mongolian Accretionary Collage
Département de Science et Technologie, Université de Guyane, ***France***

12:05 **Dr. Jérémie Soldner** (Virtual)
Petrogenesis and metamorphic records of the eastern Alashan block (NW China): insights into the making of a Cordillera-type paleo-margin
Institute of Geological Sciences, Polish Academy of Sciences, ***Poland***

12:20 **Lunch**

SESSION V

Mineral Resources and Metallogeny

Chairman: **Prof. Batkhishig Bayaraa, Dr. Ariunzaya Tsogoo**

13:30 **Keynote: Dr. Tungalag Naidansuren**
Evolution of Ore-Forming Fluids in the Tsagaan Suvarga Porphyry Cu-Mo Deposit, South Mongolia: Inferred from Stable Isotopes and Fluid inclusions
Institute of Geology, MAS, ***Mongolia***

13:50 **Dr. Huanhuan Wu**
Tectono-magmatic Framework and Gold Metallogenic Potential of the East Tianshan–Beishan Metallogenic Belt, Central Asian Orogenic Belt
Xi'an Mineral Resources Survey, China Geological Survey, ***China***

14:05 **Dr. Vasiliy Leontiev & Viktor Snezhko**
Mineral Forecasting Based on Artificial Intelligence and Empirical-Statistical Methods
The All-Russian Geological Research Institute of A. P. Karpinsky, ***Russia***

14:20 **M.Sc. Radomir Pachytel**
Reconnaissance of critical raw materials on the southwestern fringe of the Khangai Mountains – conclusions from a joint Polish-Mongolian research project
Polish Geological Institute – NRI, ***Poland***

14:35 **Assoc. Prof. John Wang**
Assessment of Geothermal Energy Resources in the Marcellus Shale
Pennsylvania State University, ***USA***

14:50 **Dr. Nikolai Gusev**
Compilation of the geological space digital models of the Greater Altai at a scale of 1:1M, aimed at forecasting ore deposits: the state of the art and proposals for intensifying scientific and practical cooperation between Russia, China, Mongolia and Kazakhstan
The All-Russian Geological Research Institute of A. P. Karpinsky, ***Russia***

15:05 Poster Session (with coffee) – see poster list

SESSION VI

Advanced Technology and Data Analysis

Chairman: **Dr. Sanchir Dorjgochoo, Dr. Vasiliy Leontiev**

15:40 Keynote: **Prof. Xixi Zhao**

The TopoAsia Initiative: A Multidisciplinary Framework for Integrating Deep Earth Dynamics and Surface Processes in Asia

Advanced Institute for Ocean Research, Tongji University, ***China***

16:00 **Dr. Viktor Snezhko**

Digital Technologies for Regional Geological Studies: Integration of Geological Data, Mapping, and Artificial Intelligence

The All-Russian Geological Research Institute of A. P. Karpinsky, ***Russia***

16:15 **Dr. Gennadiy Babin**

Monitoring the border section of the State Geological Map of the Russian Federation at a scale of 1:1,000,000

The All-Russian Geological Research Institute of A. P. Karpinsky, ***Russia***

16:30 **Dr. Olga Kovaleva**

The International Network of Karpinsky Geological Classes as a Standing Scientific and Information Platform

The All-Russian Geological Research Institute of A. P. Karpinsky, ***Russia***

16:45 **Closing Ceremony – summary of Geological Issues of Central Asia**

POSTER SESSION

Thursday 17 September, 15:05–15:40 (boards available both days)

No.	Presenter	Title
P-01	**Gerel Ochir** *Geoscience Center, MUST, Mongolia*	Contributions of the Mongolian–Soviet Joint Geological Expedition to the Study of Rare-Metal Granites in Mongolia
P-02	**Ren Qiang** *Chengdu University of Technology,* ***China***	Quantitative Paleomagnetic Constraints on the Permian Evolution of the Eastern Paleo-Asian Ocean
P-03	**Turbold Sukhbaatar** *Institute of Geology MAS, Mongolia*	Tectonic relationships of the Trans-Altai Zone and its connection to the Mongolian Altai Orogenic Belt: Implications for Paleozoic geodynamics of the Central Asian Orogenic Belt
P-04	**Pavel Hanžl** *Czech Geological Survey, Czechia*	Stratigraphy, paleontology and sedimentology of the Mesozoic formations in the Shiliin Nuruu Syncline (Gobi Altai, Mongolia)
P-05	**Cari Jonhson** *University of Utah, UT,* ***USA***	Sedimentary record of oroclinal collision and ocean closure, Buregkhangai basin of the Mongol-Okhotsk suture zone in northern Mongolia
P-06	**Paweł Urbański** *Polish Geological Institute – NRI, Poland*	Results of heavy mineral panning studies of placer sediments from the Khasagt region, Zavkhan Terrane, Mongolia
P-07	**Oyunchimeg Tserentsegmid** *Institute of Geology MAS, Mongolia*	Late Pleistocene and Holocene paleoclimate records from sediments of Achit Lake, Western Mongolia
P-08	**Uyangaa Udaanjargal** *Institute of Geology MAS, Mongolia*	Tectonic and climatic controls on Late Quaternary lacustrine sedimentation in arid Central Asia: evidence from Olgoy Lake, Mongolia
P-09	**Tuvshinjargal Battogtokh** *Institute of Geology MAS, Mongolia*	Petrogenesis of a Late Paleozoic arc-related layered ultramafic-mafic intrusion in northern Mongolia: Preliminary stratigraphic and geochemical constraints
P-10	**Luc de Hoym de Marien** *Czech Geological Survey, Prague, Czechia*	Plume-related mid-Devonian–Carboniferous magmatism along the Paleo-Pacific active margin – Gashun Nuur Complex, Mongolian Altai
P-11	**Luc de Hoym de Marien** *Czech Geological Survey, Prague, Czechia*	Permian syn-extensional Barrovian metamorphism in the Mongolian Altai
P-12	**Munkhsukh Bat-Ulzii** *Institute of Geology MAS, Mongolia*	Ediacaran magmatic arc at the northeastern margin of the Baidrag microcontinent: Whole-rock geochemistry, Sr-Nd and zircon U-Pb isotopic results

P-13	**Damdinsuren Muunuu** *MUST, Erdenet Mining Corporation SOE, Mongolia*	Geological structure of the "Erdenetiin Ovoo" copper-molybdenum group deposit
P-14	**Myagmarsuren Enkhbat** *Institute of Geology MAS, Mongolia*	Tracking the Early Phase of Closure of the Mongol–Okhotsk Ocean: Structural, Geochemical, and Zircon U–Pb Chronological Evidence from Northern Mongolia
P-15	**Baasandash Gansukh** *Institute of Geology MAS, Mongolia*	Combined structural and detrital zircon U-Pb isotopic analysis of Paleozoic sedimentary rocks from the Artsbogd Mountain range in southern Mongolia
P-16	**Elizabeth Huang** *University of Maryland, College Park, MD, USA*	REE+Y composition of different microfacies indicates preservation of highly variable paleoredox information in Cambrian phosphorites of central Asia
P-17	**Bayarmaa Batsukh** *Institute of Geology MAS, Mongolia*	Formation of the pillow lava from the Bayankhongor Ophiolite
P-18	**Dagva-Ochir Lkhagvasuren** *Institute of Geology, MAS, Mongolia* *Tatakh Khuch LLC, Ulaanbaatar, Mongolia*	Stratigraphic Framework and depositional age of Late Paleozoic–Mesozoic Sequences in Khüren Khanyn Khets, Noyon Basin
P-19	**Tserendulam Buyanjargal** *Institute of Geology MAS, Mongolia*	Geochemistry and geochronology of granitoid rocks from the Egiindavaa Complex in Khangai region, central Mongolia
P-20	**Dulguuntamir Erdenebulgan** *Institute of Geology MAS, Mongolia*	Deep-Crustal Metamorphic Records from the Zunaigol Formation: Preliminary Data

I. Paleogeography of the Central Asian Orogenic Belt and Supercontinent Cycle

The Ediacaran–Cambrian assembly of Siberomongolia: processes and mechanisms of continental construction

Karel Schulmann[1]*, *Igor Soejono*[1], *Stephen Collett*[1], *Pavla Štípská*[1], *Vojtěch Janoušek*[1], *Alexandra Guy*[1],Turbold Sukhbaatar[2], *Hanžl Pavel*[1]

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The Pangean cycle began with the Ediacaran–Cambrian assembly of Gondwana and continued through the Silurian–Carboniferous collision of Laurussia with the Variscan Collage. In a comparable manner, we propose that **Siberomongolia** was assembled during the Ediacaran–Cambrian through the progressive amalgamation of the Siberian Craton with a peri-Rodinian archipelago of continental fragments generated during the breakup of Rodinia.This prolonged evolution involved oceanic opening and closure, subduction polarity changes, arcs accretion, continental collision, and lithospheric reorganization. These events are collectively referred to as the Baikalian orogenic cycle, which should be viewed not as a single collisional event, but as a diachronous sequence of tectonic processes leading to the construction of a new continental megablock that subsequently became one of the principal constituents of northern Pangea.There is currently no consensus on the Neoproterozoic–Cambrian tectonic evolution of the Mongolian (Zavkhan, Baydrag, Tarvagatai, Erendevaa) and Transbaikalian continental blocksTuva, Sangilen, Barguzin–Vitim and Erguna, respectively) or their relationship to the Siberian Craton. However, recent geological, geochronological, isotopic, provenance, and petrological studies increasingly indicate that most of these blocks represent peri-Rodinian continental fragments that remained in close proximity to western Siberia throughout the Neoproterozoic (Wilhem et al., 2012; Xiao et al., 2015; Collett et al., 2024; Soejono et al., 2025).The principal unresolved problem is therefore not their paleogeographic affinity, but the tectonic mechanisms responsible for their progressive amalgamation into Siberomongolia.

The earliest stage is recorded by widespread lateTonian (ca. 840–780 Ma) magmatism and passive-margin successions throughout the Mongolian continental blocks, indicating their synchronous separation from the western Siberian margin during the breakup of Rodinia and the initiation of the Proto-Pacific. In contrast, subduction of the Mirovoi Ocean continued uninterrupted along the outer Rodinian margin, producing the Shishkhid, Sarkhoy and Dunzhugur magmatic arcs (Kuzmichev et al., 2015) together with Tonian medium-pressure metamorphism characterized by anticlockwise P–T–t paths typical of hot arc and back-arc environments (Ge et al., 2016; Skuzovatov et al., 2019a; Štípská et al., 2023). During the Cryogenian–early Ediacaran, subduction along the Siberian margin culminated with

the formation of an eclogitic mélange (Skuzovatov et al., 2019b) and deposition of synorogenic sedimentary basins developed along the southern Siberian margin and some Transbaikalian blocks (Gladkochub et al., 2022), while passive-margin sedimentation persisted around the southerly Mongolian blocks (Badarch et al., 2002; Bold et al., 2016; Soejono et al., 2025). At the same time, extension within the interior of the Mongolian archipelago culminated in the generation of new oceanic crust represented by the Bayankhongor ophiolite between ca. 655 and 636 Ma (Jian et al., 2010). These observations indicate that Rodinia breakup did not terminate convergence, but instead produced a long-lived tectonic configuration in which active subduction along the Siberian margin coexisted with extension and passive-margin development within the Mongolian archipelago.

A fundamental tectonic reorganization occurred during the late Ediacaran. The southern margin of the Mongolian archipelago became fringed by a discontinuous belt of suprasubduction-zone ophiolites, including the Dariv, Khantaishir, and related Lake Zone ophiolites, dated between ca. 573 and 560 Ma (Jian et al., 2014). Their geochemical characteristics indicate formation during subduction initiation in a forearc setting comparable to the modern Izu–Bonin–Mariana system (Furnes and Safonova, 2019). At approximately the same time, intra-archipelago subduction initiated along the northern margin of the Baydrag Block, as recorded by mafic magmatism and back-arc sedimentation (Sukhbaatar et al., 2024), whereas subduction continued along the Siberian margin, as demonstrated by persistent magmatism within the Shishkhid and Sarkhoy arcs. Consequently, by the latest Ediacaran, the peri-Siberian archipelago was bounded by two contemporaneous convergent margins (Zhu et al., 2024), while passive margins remained preserved locally within its interior. This tectonic configuration established the geodynamic framework for the subsequent Cambrian amalgamation of the Mongolian continental blocks.

Continental collision commenced diachronously during the latest Ediacaran and earliest Cambrian. The earliest collisional event occurred along the northern margin of the Baydrag Block, where burial of hot back-arc crust produced synorogenic metamorphism and progressive crustal thickening between ca. 565 and 540 Ma (Štípská et al., 2024). Simultaneously, collision of arc complexes with the Siberian Craton resulted in high-pressure granulite-facies metamorphism within the Chernorud Zone at ca. 530 Ma together with the development of extensive foreland basins along the southern Siberian margin (Li et al., 2023 Motova et al., 2024). At approximately the same time, the Lake Zone ophiolites were emplaced over exhumed eclogite-bearing accretionary wedges and the southern Baydrag basement (Štípská et al., 2010; Buriánek et al., 2017), while high-pressure metamorphism subsequently migrated southward to the Zavkhan Block and developed contemporaneously along the northern margin of Tarvagatai, producing additional eclogite-bearing subduction complexes around ca. 520 Ma (Zhu et al., 2023). Throughout this interval, shallow-marine sedimentation developed across large parts of the southern Siberian margin and adjacent Transbaikalian blocks (Motova et al., 2024), indicating progressive continental amalgamation in the area of the Mongolian archipelago and tectonic quiescence in the Peri-Siberian domain in the north.

The final stage of assembly occurred between ca. 510 and 500 Ma and was marked by peak-pressure granulite-facies metamorphism in the Olkhon Terrane (Gladkochub et al., 2008; Donskaya et al., 2017; Li et al., 2023), exhumation of the Baydrag orogenic core (Štípská et al., 2024) and granulite-facies metamorphism related to moderate crustal thickening along the southern Zavkhan margin (Peřestý et al., 2025). This tectonic reorganization coincided with the development of the giant Ikh Mongol Arc System (Janoušek et al., 2018) through widespread emplacement of gabbros, tonalites, and granodiorites along the southern margin of the Mongolian Collage, including the Lake Zone, while

continued subduction south of Siberia generated the Birkhin arc complex (Donskaya et al., 2017). We interpret these synchronous events as recording a continental-scale subduction polarity switch from the long-lived south-dipping Mirovoi subduction system to a newly established north-dipping Proto-Pacific subduction system.This polarity reversal transformed the previously fragmented peri-Siberian archipelago into a coherent lithospheric plate.

We conclude that the Baikalian orogenic cycle was neither a single collision nor a synchronous orogenic event, but a prolonged sequence of diachronous accretion, continental collision, and subduction reorganization extending from the latest Ediacaran to the late Cambrian.The progressive amalgamation of peri-Rodinian continental fragments with the Siberian Craton culminated in the formation of **Siberomongolia**, a new continental megablock whose subsequent evolution provided the northeastern continental nucleus of Pangea.This tectonic history represents a fundamental example of continental construction through sequential terrane amalgamation (Safonova et al., 2011), comparable in scale and significance to the Ediacaran assembly of Gondwana and the late Paleozoic construction of Laurussian–Variscan collage.

The southern Siberian craton in the Neoproterozoic: from the breakup of Rodinia to the origin of the Central Asian Orogenic Belt: geodynamics and mineral resources

Dmitrii Gladkochub[1] *, *Tatiana Donskaya*[1]

[1] Institute of the Earth's Crust, Siberian Branch of the Russian Academy of Sciences, Irkutsk, Russia

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Keywords: geodynamics, mineral resources, Neoproterozoic, Siberian Craton

The Neoproterozoic is a key period in the geological history of the Earth. It was in the Neoproterozoic that the breakup of the supercontinent Rodinia and the opening of the Paleo-Asian Ocean took place. These large-scale geodynamic processes are recorded in the geological complexes of the southern part of the Siberian craton (Gladkochub et al., 2019). It should be noted that, according to modern reconstructions (Pisarevsky et al., 2021; Gladkochub et al., 2023; Li et al., 2023), during the Mesoproterozoic, the southern flank of the Siberian craton was located in the inner regions of the Nuna supercontinent (Columbia) and all magmatic activity in this territory was controlled by the processes of intraplate extension.

The beginning of the Neoproterozoic in the south of the Siberian craton is marked by locally distributed intrusions with an age of about 1.0 Ga (Demonterova et al., 2016; Savelyeva et al., 2016), reflecting small-scale intraplate extension. Next stage of the extension (an intracontinental rifting) manifested itself on a much larger scale took place in Cryogenian.These extensional processes, which led to the breakup of the supercontinent Rodinia, correspond to the Franklin event (725–710 Ma) and are marked within the southern of the Siberian craton by numerous dike swarms of the Irkutsk Large Igneous Province or Irkutsk LIP (Gladkochub et al., 2010; Ernst et al., 2016, 2023).

Further, during the period of 645–620 Ma, in an environment of ongoing extension, minor intrusions of alkaline-ultramafic and carbonatite composition (Zhidoysky, Bolshetagninsky, Beloziminsky massifs, etc.) were intruded into the basement of the Siberian craton (Yarmolyuk et al., 2005; Savelyeva et al., 2022; Stifeeva et al., 2023; Prokopyev et al., 2024).

At approximately the same time interval (645–620 Ma), accretion-collision processes began to develop along the passive margin of the Siberian craton, which was oriented into the Paleo-Asian Ocean due to the attachment of fragments of island-arcs, oceanic islands and microcontinents to the southern margin of the craton. As a result of these processes, over a time ca. of 610–600 Ma, the passive margin was transformed into a series of foreland basins (Gladkochub et al., 2019; Powerman et al., 2015). The Neoproterozoic accretion processes resulted in the formation of an Ediacaran-age orogen along the southern margin of the Siberian craton (Gladkochub et al., 2019; Powerman et al., 2015). Active tectonic rearrangements affecting the south of the Siberian craton in the Neoproterozoic led to a variety of useful components that were accumulated in the upper part of the continental crust and formed mineral deposits.

In the Early Ediacaran,Ta-Nb ore deposits with rare-earth mineralization were associated with a series of intrusions of alkaline-ultramafic and carbonatite composition (Zhidoysky, Beloziminsky, Bolshetagninsky massifs, etc.) (Yarmolyuk et al., 2005; Savelyeva et al., 2022; Stifeeva et al., 2023; Prokopyev et al., 2024). Gold deposits of two different types are associated with the younger Ediacaran deposits of the foreland basins. In the Irkutsk zone of the Sayan-Baikal-Patom belt, the Ediacaran deposits of the Khuzhir Formation of the Moty Group contain a horizon of gold-bearing conglomerates with diamonds, which are localized in the Khuzhir deposit.This deposit is unique in its nature and the

only one in Russia belonging to an unconventional geological and industrial type of gold deposits.The source of the Precambrian diamond of the Khuzhir deposit, apparently, was the intrusions of alkaline-ultramafic and carbonatite composition located next to it (Gladkochub et al., 2026).The most famous analogue of the Khuzhir deposit in the world is the Witwatersrand gold deposit (with diamonds) in South Africa, which, however, is characterized by a much older (Archean) age of the ore-bearing strata and colossal gold reserves.

In the Bodaibo zone of the Sayan-Baikal-Patom belt, Ediacaran sedimentary sequences with black shales contain gold-platinum-sulfide mineralization, classified as "Sukholozhsky type".The most famous example of this type of mineralization is the giant "Sukhoi Log" deposit with gold reserves of more than 1,240 tons. Sedimentary rocks containing the gold mineralization were accumulated after 600 Ma, and the earliest (stratiform) pyrite containing Pb and Au was formed during sedimentation or early diagenesis about 600–575 Ma ago (Meffre et al., 2008).The age of formation of the "Sukholozhsky type" deposits proper is estimated to be 450–420 Ma (Chugaev et al., 2022). In total, in the Lena gold-bearing province (Bodaibo zone), where "Sukhoi Log" is located, identified more than ten independent deposits of the "Sukholozhsky type" with reserves of more than 50 tons of gold each.

At the same time interval (450–420 Ma), as a result of accretion-collision processes of the Early Paleozoic, hydrocarbons were squeezed out of the carbonaceous strata (black shales) of the foreland basin of the Baikal segment of the Sayan-Baikal-Patom belt in a western direction into the Siberian platform's sedimentary cover and formed deposits of the Angara-Kovykta oil and gas accumulation zone, the resources of which are estimated at 6.35 billion tons of conventional hydrocarbons.

These reported results make it possible to trace how the change of geodynamic regimes in the south of the Siberian craton in the Neoproterozoic controls the processes of deposit formation: from the stage of accumulation of useful components in the upper levels of the Earth's crust, through the stages of tectonic activation to the formation of ore and hydrocarbon deposits.

Acknowledgments

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The making of the Central Asian Orogenic Belt: Insights into the Archean tectonics

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The mechanisms governing the accretion and growth of continental crust remain a central and debated issue in solid Earth sciences.The Central Asian Orogenic Belt (CAOB), also known as the Altaids, is bounded by the Baltic and Siberian cratons to the northwest and northeast, respectively, and by the Tarim and North China cratons to the south. It is widely recognized as one of the most significant sites of Phanerozoic continental growth. This growth is closely linked to the subduction, accretion, and ultimate closure of the Paleo-Asian Ocean, as evidenced by the widespread occurrence of ophiolitic mélanges throughout the region. Nevertheless, the precise mechanisms by which this juvenile crust was generated and subsequently preserved remain elusive. To address this, we conducted a geophysical survey across key tectonic units in Xinjiang, China, to image the deep architecture of the CAOB. Our seismic data reveal multiple divergent double subduction systems beneath the East Junggar and NorthTianshan, which we interpret as resulting from successive subduction-accretion processes associated with slab rollback of the Paleo-Asian Ocean.The entire CAOB can be subdivided into three major orogenic collage systems that were finally assembled during the Late Permian to LateTriassic, without significant continental subduction or collision. By analogy, the Archean Earth, characterized by small continental nuclei separated by vast oceanic basins, may have undergone a similar mode of continental enlargement—through oceanic subduction and subsequent nucleus accretion—resembling the growth history of the Central Asian continent.

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Subduction erosion at Pacific-type convergent margins: a review and examples from the Central-Asian Orogenic Belt

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Pacific-type convergent margins (PCM) or orogenic belts form when oceanic lithosphere is subducted under intra-oceanic arcs or active continental margins. Intra-oceanic arcs built at PCMs represent major sites of juvenile crust formation on the Earth (Stern, 2010). On the other hand, PCMs are places of strong interactions between the subducting oceanic slab and subduction zone hanging wall, of which the most important is subduction erosion (Clift and Vanucchi, 2004).There are two contrasting types of PCMs – accreting and eroding (Scholl and von Huene, 2007).The accreting margins form accretionary complexes and grow oceanward.The eroding margins are characterized by the shortening distance between arc and trench, and subsequent subduction erosion of accretionary wedge, fore-arc prism, and volcanic arc.The main agents of subduction erosion are the horst-graben topography of subducting oceanic plate, orthogonal subduction of intra-oceanic arcs and ridges and accretion of oceanic rises (seamounts) (von Huene and Ranero, 2003).

The first evidence for the tectonic erosion at Pacific-type convergent margins came from seismic reflection profiles made across the Tonga and Nankai trenches in Japan. The modern Pacific is surrounded by 75% of eroding convergent margins and 25% of accreting margins (Scholl and von Huene, 2007).The fast-subducting Pacific plate provides high-rate subduction erosion of the hanging walls of the western Pacific margins. Evidence for the subduction erosion comes from the proximity of coeval accretionary and supra-subduction complexes, presence of supra-subduction magmatic rocks as blocks in exhumed serpentinite mélange, trench jumping landward and related, magmatic lulls and the disappearance of U–Pb zircon age peaks in younger clastic rocks. For example, the Costa Rica consuming boundary in South America witnesses high rates of sediment destruction (Vanucchi et al., 2016), and the Cretaceous Shimanto accretionary prism in Japan is spatially adjacent to the coeval granitoids of the Ryoke belt suggesting that older accreted units were eroded (Safonova et al., 2015). Therefore, a very challenging issue of the reconstruction of fossil magmatic arcs is the probable disappearance of arc igneous rocks from geological records due to subduction erosion.

The present Western Pacific is a classic analogue of the Paleo-Asian Ocean (PAO), the suturing of which resulted in the formation of the Phanerozoic Central Asian Orogenic Belt (CAOB) (Safonova et al., 2011). Accordingly, we suggest that the processes of subduction erosion were probably active at the PAO active margins. Evidence for this comes from the Chatkal-Atbashi arc in the middle Kyrgyz Tianshan (Alexeiev et al., 2016), the Itmurundy and Tekturmas zones of central Kazakhstan (Safonova et al., 2024, 2025), Ulaanbaatar accretionary complex in Mongolia (Savinskiy et al., 2022) and Char zone in eastern Kazakhstan (Safonova & Perfilova, 2023).The Chatkal-Atbashi complex includes coeval and spatially adjacent Early Devonian arc granitoids, ophiolites and accretionary units. In the Itmurundy and Tekturmas zones, the middle-late Cambrian igneous rocks of supra-subduction origin have been diagnosed only as blocks in serpentinite mélange. In addition, in the Itmurundy and Tekturmas zones, the accreted oceanic units are located very close to the coeval supra-subduction complexes.The Itmurundy, Tekturmas, and Char zones in Kazakhstan and Ulan-Baatar AC in Mongolia all host thick greywacke units of mafic to andesitic composition, which detrital zircons those greywackes show unimodal U-Pb age curves, disappeared older peaks in younger sediments and positive epsilon Hf value. All these features

suggest that that several magmatic arcs, at least the Cambrian and Devonian, that once existed in the PAO were eroded.Therefore, the processes of subduction erosion in the PAO were similar to those in the modern Circum-Pacific, for example, over the Guatemala-Costa Rica-Chile (eastern Pacific),Tonga (SW Pacific) and Nankai-Japan (western Pacific) subduction zones (von Huene and Ranero, 2003). Understanding the mechanisms and implications of subduction erosion is fundamental to model the construction and destruction of continental crust. Supported by NSFC project # W2431031.

Cryptic basement as the clue to unraveling orogenic configuration: Case studies from the Variscan and Central Asian orogenic belts

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Keywords: Orogenic architecture, Precambrian paleogeography, Variscan Belt, Mongolian Collage

Our understanding of the complex architecture, geodynamics and paleogeography of major crustal domains within orogenic belts are often hindered by poorly constrained primary relationships. These uncertainties can be overcome through knowledge about the age, nature, and provenance of relics of an ancient continental crust preserved within the younger units. This perspective on orogenic belts is illustrated with two contrasting examples from Variscan Europe and Central Asian Orogenic Belt. Combining field observations, U–Pb and Hf zircon isotopic and whole-rock geochemical data, we studied sedimentary and magmatic records in the preserved pre-orogenic basement fragments and addressed the above-mentioned questions.

The first case examines the collisional Variscan Belt, considered as composed of crustal blocks derived mostly from the northern Gondwana (Nance and Murphy, 1994). The basement of the Moldanubian Zone in central Bohemian Massif represents one of these peri-Gondwanan terranes and is traditionally assumed to be of West African origin (Tait et al., 1997). Based on the zircon age and Hf isotopic data and geochemistry, we identified in the Moldanubian Zone two contrasting magmatic suites (syn-collisional at c. 2.1 and rift-related at c. 1.3 Ga) and three sedimentary sequences (late Paleoproterozoic, late Mesoproterozoic and Ediacaran–Cambrian). The presence of Mesoproterozoic magmatism and detritus appears to rule out primary affinity of the Moldanubian Zone to the West African Craton. Timing of pre-Ediacaran magmatism and deposition coincided with the formation and break-up of the Columbia supercontinent (Evans and Mitchell, 2011), and data comparison with potential source cratons points to a likely Baltican affinity. In contrast, the age pattern of the Ediacaran–Cambrian metasedimentary sequence indicates an affinity to the northern African part of Gondwana. This change in the provenance signal between the late Mesoproterozoic (Baltica) and Ediacaran (northern Africa) implies a plate tectonic relocation that happened in the intervening timeframe. It is proposed that the Moldanubian Zone, and potentially other peri-Gondwanan terranes, were rifted-off the Baltican part of the Columbian margin and accreted to their 'traditional' Ediacaran–early Paleozoic position on the northern margin of Gondwana.

The second example addresses the accretionary Mongolian Collage, centered around a series of Precambrian continental blocks (Xiao et al., 2015). These microcontinents are encircled by the Ediacaran–early Paleozoic accretionary complexes of the Lake Zone. This wide zone consists of passive

margin sequences, ophiolites, supra-subduction complexes and magmatic arcs (Badarch et al., 2002). The Dariv Range, located on the south-western margin of the Lake Zone, is primarily composed of ophiolitic and arc-related rocks (Khain et al., 2003; Dijkstra et al., 2006). However, it also includes high-grade basement, where we discovered widespread late Tonian (c. 825–787 Ma) rift-related magmas that intruded into late Paleoproterozoic–early Tonian sediments. The age and composition of metaigneous rocks and the detrital zircon age and Hf isotopic patterns of metasedimentary rocks match those known from the Mongolian Collage microcontinents (Bold et al., 2016; Soejono et al., 2023, 2025; Collett et al., 2025). Thus, the Precambrian basement of the Lake Zone is interpreted as representing a preserved older crustal fragment, likely derived from the nearest Zavkhan Block. We conclude that the Lake Zone, together with other microcontinental blocks within the Mongolian Collage represented a Tonian hyper-extended and fragmented passive margin of Rodinia (Li et al., 2008). It was subsequently reconstructed through a complex series of supra-subduction systems during the Ediacaran and early Paleozoic.

These two examples, one from collisional and one from accretionary orogens of contrasting ages, demonstrate that insight into the ancient and relict (or cryptic) basement is essential for a complete understanding of the younger orogenic configuration. Pre-orogenic basement rocks, usually only rarely exposed in the orogenic structure, can thus serve as key pieces of evidence in the reconstruction of orogenic systems.

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Ediacaran Accretionary Events in the Northern Central Asian Orogenic Belt

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Keywords: accretion, Ediacaran, Central Asian Orogenic Belt, Siberian Craton

One of the key stages in Siberia's evolution is the time interval 715–650 Ma, when the Paleo-Asian Ocean opened between Siberia and Laurentia as a result of the breakup of the Rodinia supercontinent (Gladkochub et al., 2019). The closure of the Paleo-Asian Ocean in its "Siberian" part and the formation of the northern Central Asian Orogenic Belt (CAOB) occurred in two stages. The first stage corresponds to the Ediacaran (610–580 Ma), and the second stage was in the Late Cambrian–Early Ordovician (500–450 Ma).

In our report, we will discuss in detail the events of the Ediacaran accretionary stage. This stage related to the accretion of Neoproterozoic island-arcs, oceanic islands of the Paleo-Asian Ocean, as well as the fragments of older island arcs and continental blocks into large Neoproterozoic composite superterranes and their joining to the Siberian Craton with the formation of the Siberian paleocontinent (Rytsk et al., 2011; Ruzhentsev et al., 2012; Powerman et al., 2015; Gladkochub et al., 2019). The largest fragments of such Neoproterozoic composite superterranes in modern structure of the northern CAOB are the Baikal-Muya belt (superterrane) in the northeast and the Kan-Arzybey superterrane in the southwest. The final accretion of these Neoproterozoic superterranes to the Siberian Craton was at 610–580 Ma. The indicators of this event in the Baikal-Muya superterrane are 630–585 Ma syn-collisional and post-collisional granitoids (Rytsk et al., 2011, 2017; Andreev et al., 2022). For the Kan-Arzybey superterrane, the time of metamorphic events was about 600 Ma and the post-collisional granitoid magmatism at about 560 Ma (Nozhkin et al., 2007). Metamorphic events of similar age (615–600 Ma) also related to Ediacaran accretionary stage were documented in the Predivinsk terrane of the Yenisei Ridge (Nozhkin et al., 2016).

We identified one more fragment of the Neoproterozoic superterrane (Zunduk terrane), which was accreted to the Siberian Craton in the Ediacaran. The Zunduk terrane is located in the eastern part of the northern CAOB to south of the Baikal-Muya belt. Previously, this terrane was considered as part of the Early Paleozoic Olkhon terrane (Fedorovsky et al., 2005; Donskaya et al., 2017). The Zunduk terrane consists of the fragments of Proterozoic continental blocks and Neoproterozoic island-arcs (Donskaya et al., 2017), which were united into a single superterrane and accreted to the Siberian Craton about 600 Ma. The indicator of the final accretion of the Zuduk terrane to the craton margin is 580 Ma granitoids.

In the modern structure of the northern CAOB, fragments of Neoproterozoic composite superterranes remain only in its eastern and western parts. However, at the time of their joining to the craton, similar Neoproterozoic superterranes were apparently located along the entire southern margin of the Siberian Craton (Gladkochub et al., 2019; Metelkin et al., 2012). Indicators of these events are the Ediacaran foreland basins, fragments of which are located in the southern Siberian Craton (Sovetov, 2018;

Powerman et al., 2015; Gladkochub et al., 2019). During the second accretionary stage (500–450 Ma) the Late Ediacaran – Cambrian island-arcs of the Paleo-Asian Ocean joined the southern part of the Siberian paleocontinent with the formation of the Baikal collisional metamorphic belt (Donskaya et al., 2000, 2017; Ruzhentsev et al., 2012; Rytsk et al., 2009; Metelkin et al., 2012). Ediacaran Neoproterozoic composite superterranes located near the southern part of the Siberian Craton were partially fragmented and relocated.The final structure of the northern CAOB exhibits some zonation: fragments of Ediacaran superterranes are located in the eastern and western parts, and fragments of Late Ediacaran–Cambrian terranes in its southern parts.The indicator of the final stage of the formation of the northern CAOB are Ordovician post-collisional granitoids (Rudnev, 2013).

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II. Mongolian Collage and Tectonics

Establishing the Continental Core: an analysis of terrane transitions in the Mongolian collage

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Keywords: Core of the supercontinent; Mongolian tectonic terrane, Accretionary Orogenic Belt, CAOB

Mongolia is a landlocked country that spans approximately 1.56 million square kilometers. Although it is not currently recognized as the geological core of the microcontinent, due to its specific formations and tectonic origins, it occupies a significant central position within the Central Asian Orogenic Belt (CAOB), often referred to as the Altaids (Sengor & Natalin, 1996). The geographical location of the country, remote from the oceans and at the intersection of significant macro-scale collisional events, including the closure of existing oceans, places the Mongolian lithosphere on a path to transition from being an ancient accretionary orogeny belt to serving as the central structural nucleus of a future supercontinent. Furthermore, the CAOB is acknowledged as one of the largest accretionary orogenic belts globally (Jahn et al., 2004; Windley et al., 2007). This extensive accretionary orogenic belt, which incorporates Mongolia, is positioned between ancient cratons, namely the Siberian craton to the north and the North China and Tarim cratons to the south (Sengor & Natalin, 1996; Windley et al., 2007). This region has witnessed significant geological evolution as a result of the assembly of these microcontinents, leading to the formation of a large-scale accretionary orogenic belt. As a result, the whole Mongolian landscape preserves nearly all known geotectonic units, including fragments of microcontinents, various types of arcs, accretionary complexes, both active and passive margins, and ophiolites (Badarch et al., 2002; Tomurtogoo, 2014). This diverse geological assembly, referred to as the Mongolian collage (Xiao et al., 2018) is distinguished by a significant large-scale bending shape known as the Mongol-Orocline structure (Schulmann et al., 2025; Xiao et al., 2015). Over the past five decades, a number of esteemed geoscientists have developed tectonic maps of Mongolia (Badarch et al., 2002; Tomurtogoo, 2014; 2017; Zonenshain et al., 1978). Among these contributions, the work by Badarch (2002) stands out for its significance, as it identifies and categorizes 44 distinct terranes, making it the most frequently cited study in the global literature. The terrane concept posits that continents develop through the accretion of fault-bounded, exotic crustal fragments, each possessing unique stratigraphic and tectonic histories that differ from those of neighboring landmasses. Nonetheless, Mongolia is primarily characterized by an accretionary orogenic system. Recent studies indicate that the reworking of the crust in this region is influenced by dynamic geological processes, such as slab rollback (Jiang et al., 2019; Soejono et al., 2021; Sukhbaatar et al., 2022). Consequently, applying the terrane concept to classify this region presents considerable challenges. The actual extent of many of these terranes is frequently overestimated due to structural fragmentation and faulting resulting from later tectonic activity. Furthermore, the framework established by Badarch et al. (2002) provides important knowledge into Mongolian tectonics. However, its application is complicated by significant crustal reworking. The widespread faulting and fragmentation resulting from repeated geodynamic events and subsequent tectonic activities underscore the need for a revised tectonic map that accurately reflects the post-accretionary structural changes in the region. These unique geographical, geological, and geotectonic

positioning offers a substantial opportunity to establish a natural laboratory that could attract researchers and scientists on a global scale. This initiative would be particularly valuable for those focused on the study of both ancient and juvenile continental crust formation, including their mechanisms and the associated mineral deposits.

Petrogenesis and Metallogenic Implications of Li–F Granites in Mongolia: Constraints from Geochemistry, Mineral Chemistry and Geochronology

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Keywords: Rare metal Li-F granite, Mongol-Okhotsk Belt, U–Pb geochronology; mineral chemistry, Sn-W-Ta-Nb-Li mineralization, Mongolia

Introduction and Geological Setting

Li-F granites represent highly fractionated rare-metal granitoids characterized by extreme magmatic differentiation, fluorine enrichment, and elevated concentrations of economically important metals such as Li, Sn, W, Nb andTa. In Mongolia, Li-F granites occur within the Mongol-Okhotsk orogenic system of the Central Asian Orogenic Belt. This region records a geodynamic evolution involving subduction, collision, and post-collisional extension from the late Paleozoic to the early-late Mesozoic. Following closure of the Mongol-Okhotsk Ocean and continental collision, the region experienced extensive crustal reworking and voluminous granitoid magmatism. Available geochronological data indicate two principal Mesozoic episodes of rare-metal magmatism.The first is represented by granitoid complexes and Li-F granites emplaced during the LateTriassic–Early Jurassic (ca. 230–195 Ma). A younger episode occurred during the Late Jurassic–Early Cretaceous (ca. 145–120 Ma) and is characterized by evolved biotite granites, leucogranites, and subvolcanic ongonites (Kovalenko et al., 1971; Antipin et al., 2016). Both episodes are widely interpreted to reflect post-collisional to extensional tectono-magmatic evolution following closure of the Mongol-Okhotsk Ocean. Several Li-F granite bodies occur along the margins of the Khentei Batholith, a composite intrusive complex dominated by granodiorite and quartz diorite with subordinate mafic intrusions.The Li-F granites occur as small plutons, apophyses, and dyke-like bodies representing the most evolved stages of multistage magmatic systems, or as independent plutons (Kovalenko et al., 1971; Antipin et al., 2016). Mineralogically, the Li-F granites consist of microcline (amazonite), albite, quartz, and Li-bearing micas, with accessory topaz, fluorite, cassiterite, columbite–tantalite, monazite-(Ce), uraninite, and thorite. Subvolcanic equivalents (ongonites) represent fine-grained porphyritic rocks of the same evolved magmatic system. Together with pegmatites, greisens, hydrothermal veins, albitites, and microclinites, they constitute an integrated magmatic–hydrothermal system with rare-metal mineralization. This study integrates a review of Mesozoic Li–F granites in Mongolia with new geochemical, mineralogical, and geochronological data from key rare-metal granite complexes.

Geochronology

Zircon U–Pb geochronology indicates that granitoid magmatism of the Khentei Batholith occurred over a prolonged interval from ca. 230 to 195 Ma. Early intrusive phases yield ages of ~230–210 Ma, while more evolved granitic phases, including Li–F granites, crystallized between ~213 and 195 Ma. This temporal evolution reflects progressive fractional crystallization and crustal reworking during post-collisional extension in the Mongol–Okhotsk orogenic system. Li–F granites represent the terminal

stages of magmatic differentiation and are associated with peak enrichment in rare metals, with Sn-W-Ta-Nb-Li mineralization interpreted as a late-stage product of evolved melts and exsolving F-rich magmatic–hydrothermal fluids.

Metallogenic System

Li-F granite systems are closely associated with Sn-W,Ta-Nb, and Li mineralization. Ore assemblages include quartz veins, greisen zones, pegmatites, lepidolite–albite, amazonite albite granites, and albitites and microclinites formed during late-stage magmatic–hydrothermal evolution.Ta-Nb mineralization is mainly related to lepidolite–albite granites and albitized greisen systems hosting columbite–tantalite. Unidirectional solidification textures (UST) in Sn occurrences indicate crystallization from volatile-rich residual melts, supporting a magmatic–hydrothermal origin for early ore-forming processes. Rare-metal mineralization is spatially concentrated within evolved plutons, where Sn–W and Ta–Nb zones are locally associated with related placer deposits. Strong enrichment in Li, Rb, Cs, Sn, W, Nb,Ta, and F, together with low K/Rb, Zr/Hf, and Nb/Ta ratios, reflects extreme fractional crystallization and efficient incompatible element concentration in residual melts (Gerel, 2021). Collectively, Li–F granites, ongonites, pegmatites, and greisens constitute a genetically linked, long-lived magmatic–hydrothermal system responsible for Sn-W-Ta-Nb-Li metallogeny in Mongolia.

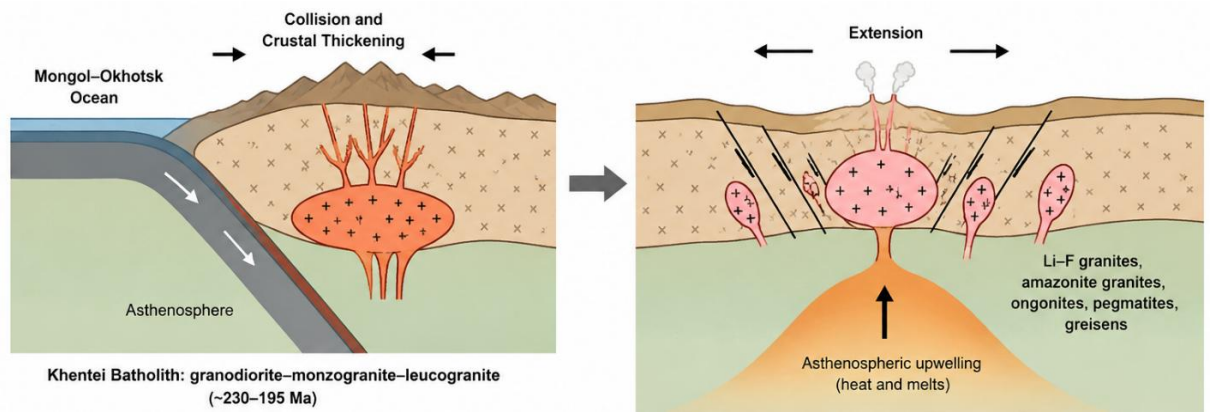


Figure 1. Conceptual model of the Early Mesozoic tectono-magmatic evolution of the Khentei region: (a) subduction–collision and emplacement of the Khentei Batholith; (b) post-collisional extension and generation of Li–F granites.

Petrogenesis

The Li–F granites are interpreted as highly fractionated intrusive facies spatially related to collisional granitoids of the Mongol–Okhotsk belt. Slightly negative to positive εNd(t) values (-1.1 to +1.4) indicate contributions from relatively juvenile crustal components within the Central Asian Orogenic Belt. Fluorine played a key role in magma evolution by lowering viscosity, enhancing element mobility, and stabilizing highly evolved residual melts. Subsequent exsolution of F-rich fluids promoted the formation of greisen, pegmatite, and albitite systems hosting rare-metal mineralization. Overall, Li–F granites, ongonites, pegmatites, and greisens represent genetically linked products of a long-lived magmatic–hydrothermal system responsible for Sn-W-Ta-Nb-Li metallogeny in the Khentei region. Geodynamically, the system developed during post-collisional evolution of the Mongol-Okhotsk orogen following ocean closure.Transition from compression to extension induced lithospheric relaxation, crustal anatexis, and emplacement of voluminous granitoids (Fig.1). Progressive fractional crystallization of crust-derived magmas, possibly with minor mantle heat and source input, generated F-rich residual melts from which Li–F granites and related subvolcanic rocks crystallized.

Conclusion

Li–F granites of Mongolia represent highly fractionated, fluorine-rich granitic systems emplaced during Late Triassic–Early Jurassic post-collisional magmatism. They are characterized by extreme fractional crystallization and strong enrichment in Li, Rb, Cs, Sn, W, Nb, and Ta, together with depletion in Ba, Sr, and Eu. Mineral chemistry of Li-bearing micas and whole-rock geochemistry indicate advanced evolution under fluorine-rich conditions. Zircon U–Pb ages confirm their link to the late-stage evolution of the Khentei Batholith. These granites are closely associated with Sn-W-Ta-Nb-Li mineralization hosted in pegmatites, greisens, and albitites, highlighting a strong genetic relationship between Li–F granite evolution and rare-metal ore formation. They represent key indicators of fertile magmatic systems and important exploration targets in Mongolia.

Records of polyphase orogenesis and the transition to intraplate deformation in southeastern Mongolia

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Keywords: intraplate deformation, orogenesis, East Gobi Fault Zone

The geology of the Central Asian Orogenic Belt in Mongolia provides insight into the growth and evolution of continents and conditions that favor intracontinental deformation. Southeastern Mongolia is part of a vast accretionary complex involving Paleozoic arc terranes that collided with North China during closure of the Paleo-Asian Ocean. The NE–SW trending East Gobi Fault Zone (EGFZ), a lithospheric-scale fault zone that records a complex history of post-collisional polyphase Triassic–Quaternary intraplate deformation. This study highlights results from integrated field, microstructural and $^{40}Ar/^{39}Ar$ and U/Pb geochronological data that place temporal constraints on the transition from ocean closure to intraplate deformation.

In the southern EGFZ (Figure 1), Lower–Upper Permian turbidite and shallow-marine clastic successions mark final closure of a remnant ocean basin between the Paleozoic arc terranes and the North China block (Johnson et al., 2008; Heumann et al., 2012). The strata lie unconformably above or in fault contact with Carboniferous and older rocks to the south, including metasediments and marbles of higher strain and metamorphic grade. $^{40}Ar/^{39}Ar$ step heating analyses of hornblende from a granitoid and white mica from muscovite schist along the SW and S margins of the turbidites yield plateau ages of 274 and 273 Ma, respectively, a time that overlaps with deposition of the shallow marine clastics. White mica from mylonitic rocks along the NW margin of the Nomgon block yielded $^{40}Ar/^{39}Ar$ spectrum with a loss profile and 234 Ma weighted mean age. At Bulgan Uul, an offset correlative of the Nomgon section across the EGFZ, the transition from marine to terrestrial sedimentation is cross-cut by an intermediate–mafic dike swarm for which hornblende yielded a 245 Ma $^{40}Ar/^{39}Ar$ plateau age (Heumann et al., 2012). To the north and structurally below a carbonate klippe, hornblende from a boudinaged mafic dike yielded a 227 Ma $^{40}Ar/^{39}Ar$ weighted mean age. Biotite from the same boudin and its host paragneiss both yield complicated spectra but are consistent with Late Triassic metamorphism and deformation.

Farther northeast in the EGFZ, the history of magmatism, orogenesis, and intraplate shearing is particularly well recorded by metamorphic tectonites of the northern Tavan Har basement block. LA-ICP-MS isotopic and chemical analyses of CL-imaged zircon cores and rims define four U-Pb age populations that are interpreted to represent: 1) Late Carboniferous–early Permian arc accretion and 2) late Permian–Early Triassic collisional orogenesis. 3) Ages ~225 Ma record the early stages of an intraplate ductile shear zone that reactivated the inherited late Paleozoic crustal structure. 4) The youngest population of zircon ages records synkinematic intrusion of leucocratic melts into the shear zone ca. 217 Ma (Taylor et al., 2013; Stypula and Webb, 2010). U-Pb titanite data from amphibolites and amphibolite-facies gneisses yield an older population c. 274, and two younger populations at 244 and 224 Ma. The rocks of northern Tavan Har record polymetamorphism and anatexis during residence of the Carboniferous arc and forearc protoliths in an apparently hydrous lower-crustal environment. The Late Triassic U-Pb ages are consistent with $^{40}Ar/^{39}Ar$ data that constrain the timing of amphibolite-facies sinistral shear in the EGFZ. Taken together and integrated with ongoing studies, these data along strike of the EGFZ suggest that collisional orogenesis continued in SE Mongolia until the Early Triassic and that the transition to intraplate sinistral shear along NE-trending EGFZ occurred by the Late Triassic (Carnian).

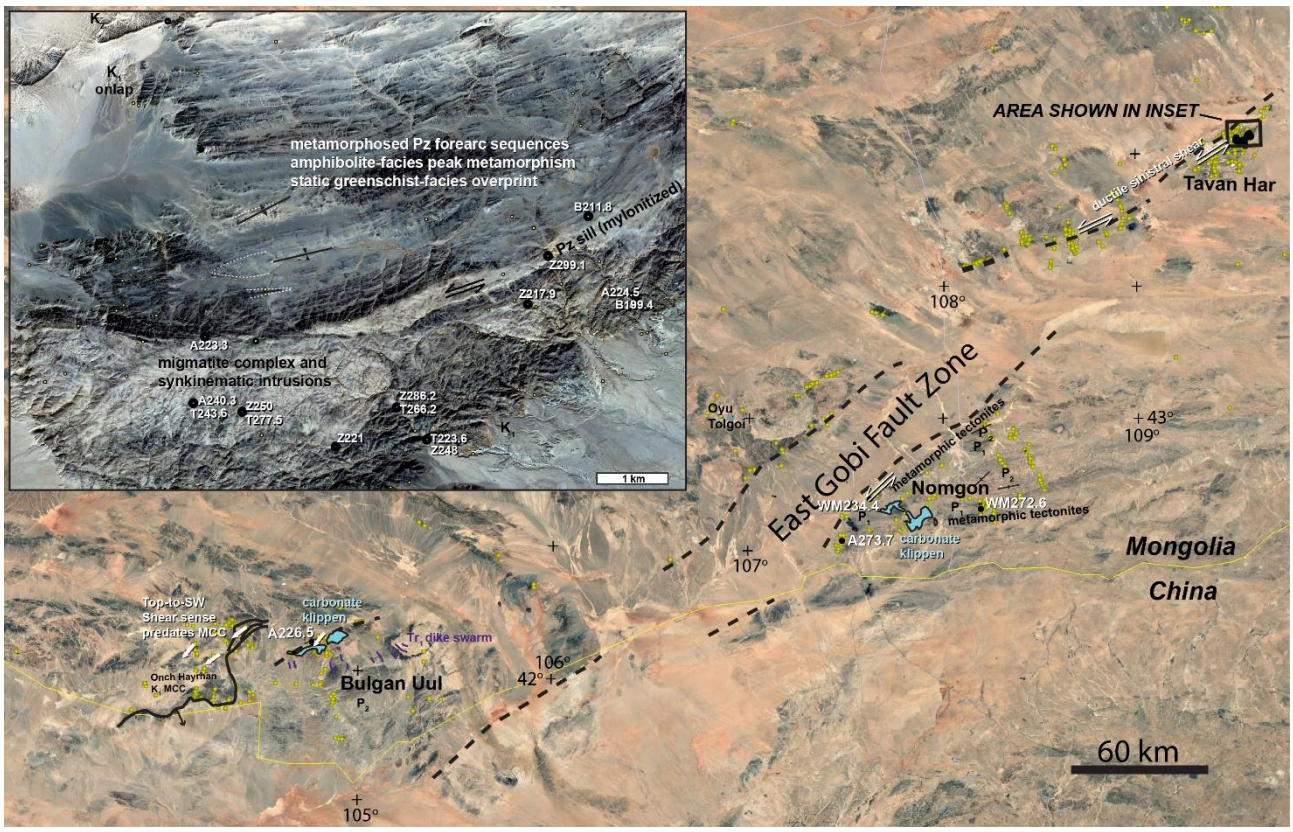


Figure 1. Google Earth imagery with locations of features unpublished geochronology results noted in the abstract. $^{40}Ar/^{39}Ar$ geochronology: A = amphibole, B = biotite, WM = white mica; U-Pb geochronology: T = Titanite, Z = Zircon; ages are reported in Ma. Dots represent field and sample localities.

Acknowledgments

This presentation is dedicated in fond memory of G. Badarch and Ch. Minjin. This research is the result of many years of field work and analyses largely supported by NSF grants EAR-9708207, 9614555, 0537318, 0537165, and 0929902. It has benefited greatly from long term collaborations with Cari Johnson and the contributions of many other mentors, collaborators, logistics leaders, students, drivers, and cooks, etc.—too many to be named here and only in part represented in citations.

Ophiolites in Mongolia: Implications for the Spatiotemporal andTectonic Evolution of the CAOB

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Keywords: Ocean formation, Subduction initiation,Tracing ancient oceans

Ophiolites across Mongolia provide key constraints on the subduction-accretion processes and multi-oceanic evolution within the dominant Central Asian Orogenic Belt (CAOB). Based on spatial distribution and geology, Mongolian ophiolites are classified into six distinct zones: Central Mongolian, Mongol-Okhotsk, Lake, Mongol Altai, Trans-Altai, and South Gobi. Geochronological data demonstrate five principal magmatic pulses spanning 1.02 Ga to 255 Ma: (1) 1.02–0.93 Ga (Mirovian Ocean generation); (2) 800–780 Ma; (3) 655–560 Ma (Mirovian subduction and accretion); (4) 529–500 Ma (Paleo-Asian Ocean supra-subduction zone [SSZ] origin); and (5) 350–255 Ma (Late Paleozoic PAO closure and Mongol-Okhotsk Ocean subduction initiation). We propose that the closure of the Mirovian Ocean (~540–520 Ma) directly triggered subduction initiation in the Paleo-Asian Ocean (PAO). Furthermore, regional belt correlations link the Gurvansaikhan-Manlay belt with the Armantai belt (East Junggar, China), and the Edren-Altan Uul belt with the Kalameili and Hegenshan-Erenhot ophiolite systems.

Introduction

Ophiolites mark ancient suture zones and record the full lifecycle of oceanic lithosphere from rifting and seafloor spreading to subduction initiation, arc evolution, and terminal obduction (Metcalf and Shervais 2008; Dilek and Furnes 2011). Within the Central Asian Orogenic Belt (CAOB) the world's largest Phanerozoic accretionary orogen (e.g., Xiao et al., 2018). Mongolia occupies a pivotal central position. Despite extensive occurrences of ophiolitic fragments, precise geodynamic triggers, ocean-basin transitions, and lateral belt correlations between Mongolia and adjacent Chinese terranes have remained debated due to inconsistent isotopic ages and high-resolution geochemical datasets. This study synthesizes spatial, geochemical, and geochronological parameters across Mongolian ophiolites to reconstruct the geodynamic framework of the CAOB.

Zonal Classification and Geochronological Framework

Mongolian ophiolites are categorized into six zones (Fig. 1):

- Central Mongolian Zone: Includes the Bayankhongor belt (665–636 Ma SSZ/OIB-like assemblages) and the Kherlen belt (510–501 Ma SSZ/E-MORB type) (Jian et al., 2010a; Maio et al., 2016).
- Mongol-Okhotsk Zone: Represented by the Adaatsag (325–319 Ma), Khukh Davaa (321–314 Ma) and Erdenedalai (ca 350 Ma) orogen (Zhu et al., 2017, 2023a, 2026) SSZ ophiolites marking Carboniferous subduction initiation, and the Permian Monhkhan back-arc ophiolite (~255 Ma)(Zhu et al., 2023b).

- Lake Zone: Contains ancient fragments including Dunzhugur (~1.02 Ga), Erdene Uul (~970 Ma), and Kharuul (~960–930 Ma), as well as Ediacaran–Cambrian SSZ systems such as Khantaishir (573–568 Ma) and Dariv (571–560 Ma) (Buriánek et al., 2017; Janoušek et al., 2018; Jian et al., 2014; Kovach et al., 2021; Stipska et al., 2010;Tomurtogoo 2012).
- Mongol Altai & Gobi Altai Zones: Dominated by Cambrian accretionary wedge remnants, including the Ulgii (529 Ma forearc-type), Hanulaan (~520 Ma), and Biluutiin Ovoo (525–503 Ma) ophiolites (Zhu et al., 2024).
- Trans-Altai Zone (TAZ): Comprises three dominant belts: Gurvansaikhan-Manlay (528–501 Ma), Edren-Altan Uul (Devonian–Carboniferous), and Enshoo (Carboniferous) (Kröner et al., 2010; Rippington e al., 2013). South Gobi Zone: Defined by the Permian Solonker ophiolite (296–260 Ma), representing the final closure site of the Paleo-Asian Ocean (Chen et al., 2017; Fu et al., 2025).

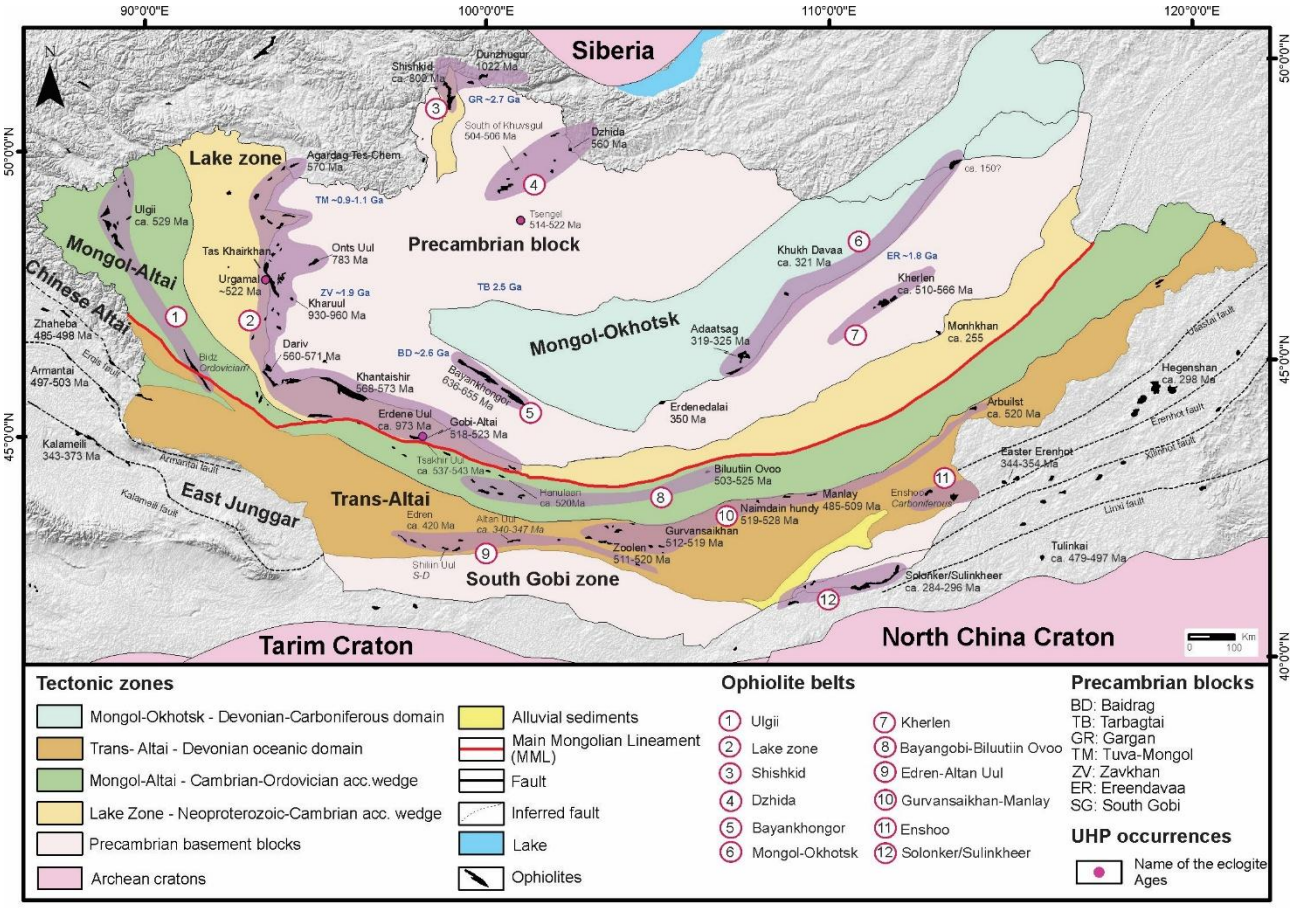


Figure 1.Tectonic map of the Mongolian collage, showing the distribution of ophiolites, major tectonic zones, and ophiolite belts in Mongolia and adjacent areas of China.This region forms the central portion of the central Asian orogenic belt (CAOB). Modified from (Badarch et al. 2002; Parfenov et al. 2004; Guy et al. 2020).

Tectonic Evolution of Paleo-OceansThe lifecycle of three distinct oceanic domains is documented: Mirovian Ocean (1.02 Ga – 520 Ma): Represents the Mirovoi surrounding Rodinia. Initial active-margin spreading and intra-oceanic subduction occurred during 1.02–0.93 Ga, followed by Cryogenian-Ediacaran arc-building and oceanic island accretion (e.g., Bayankhongor) (e.g., Buriánek et al., 2017; Zhu et al., 2024).Terminal closure at ~540–520 Ma is marked by a >1000 km Cambrian eclogite belt.

Paleo-Asian Ocean (PAO; ~530–255 Ma): Closure of the Mirovian Ocean triggered a subduction-jump/initiation event in the PAO, forming widespread 529–500 Ma SSZ ophiolites across western and southern Mongolia (e.g., Zhu et al., 2024). Continuous southward subduction-accretion persisted throughout the Paleozoic, culminating in soft collision along the Solonker suture zone during the Late Permian (~260 Ma)(Jian et al., 2010b). Mongol-Okhotsk Ocean (MOO; Pennsylvanian – Jurassic): Subduction initiation occurred in the Early Pennsylvanian (~325 Ma), producing IBM-forearc-type sequences (Adaatsag).The ocean subsequently closed in a scissoring/zipping style from west to east during the Middle-Late Jurassicorogen (Zhu et al., 2023b).

Transboundary Belt Correlations

Spatial and geochemical matching allows correlation of southern Mongolian belts into East Junggar and Northern China: The Gurvansaikhan-Manlay belt extends westward to link with the Zhaheba-Armantai ophiolite belt (503–497 Ma) in East Junggar. The Edren-Altan Uul belt extends westward along the Gobi-Tianshan fault to connect with the Kalameili belt (East Junggar) and south-eastward to the Enshoo belt, which directly correlates with the Erenhot-Hegenshan suture system (310–295 Ma) in Inner Mongolia, China.

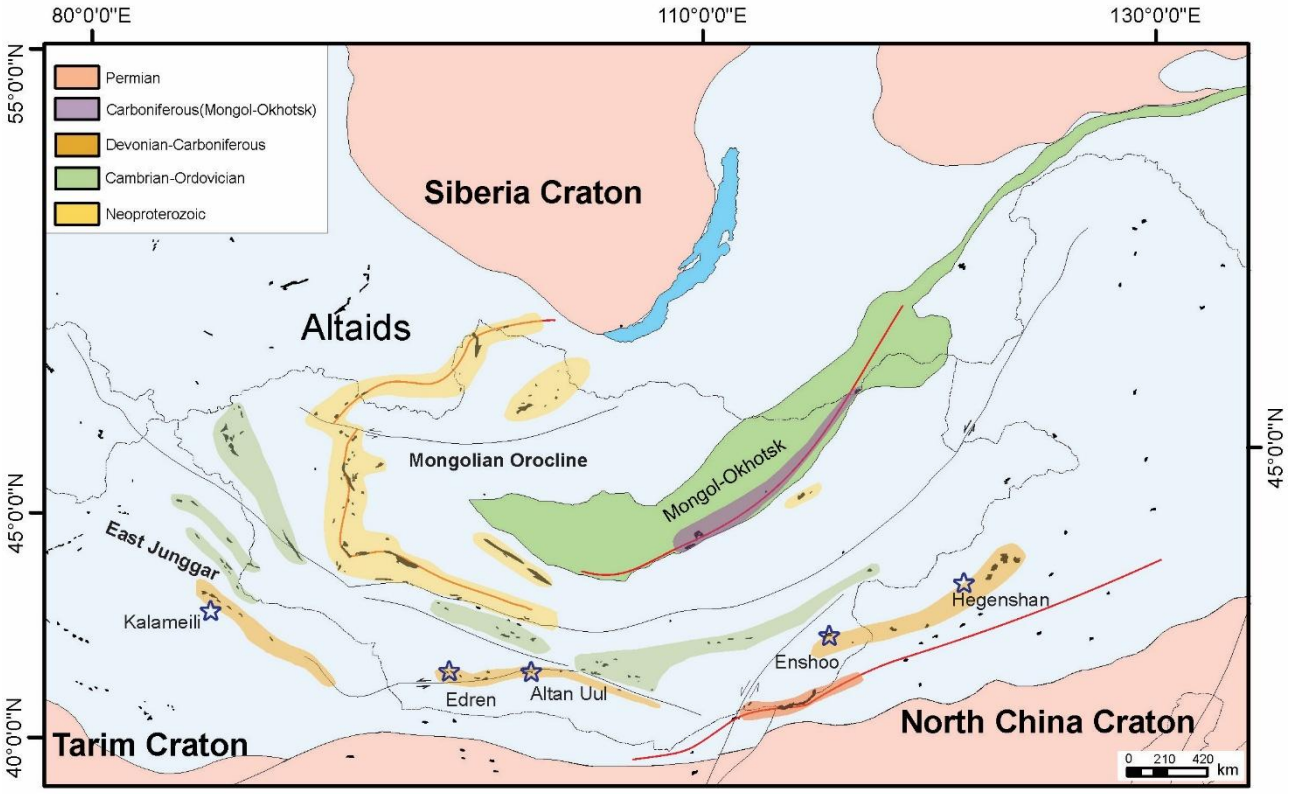


Figure 2. Age of the ophiolite belts in Mongolia the adjacent areas in China, such as Chinese Altai, east Junggar, and Hegenshan belts.

Conclusions

Mongolian ophiolites span ~1.02 Ga to 255 Ma and record five major periods of ocean crust generation and subduction initiation. Evolution involved three sequential ocean systems: Mirovian, Paleo-Asian, and Mongol-Okhotsk. Mirovian closure (~540–520 Ma) directly induced PAO subduction initiation. Ophiolite belts in southern Mongolia provide direct continuous links across East Junggar and Inner Mongolia (China), framing a combined Late Paleozoic tectonic collage.

Funding

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From Chaotic Accretion to Ordered Cratonization: The Altai Story Told by Deformation–Metamorphism–Magmatism

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Keywords: Accretionary wedge, Crustal anatexis, Tectonic switching, Subduction retreating, Altai orogenic belt

The nature of the Altai domain has long been debated. A recent integrated study of the Mongolian Altai documented a giant Ordovician metasedimentary succession composed of immature terrigenous and volcanogenic material with graywacke affinities; detrital zircon U–Pb ages are dominated by ca. 500 Ma arc-related sources, indicating an active continental margin. This succession, together with its Chinese equivalents, defines a constituent part of an early Paleozoic volcano-sedimentary accretionary wedge (namely the Altai accretionary wedge, Figure 1) riming the active margin of the Mongolian Precambrian continental blocks (e.g., (Y. D. Jiang et al., 2017; Xiao et al., 2009)).

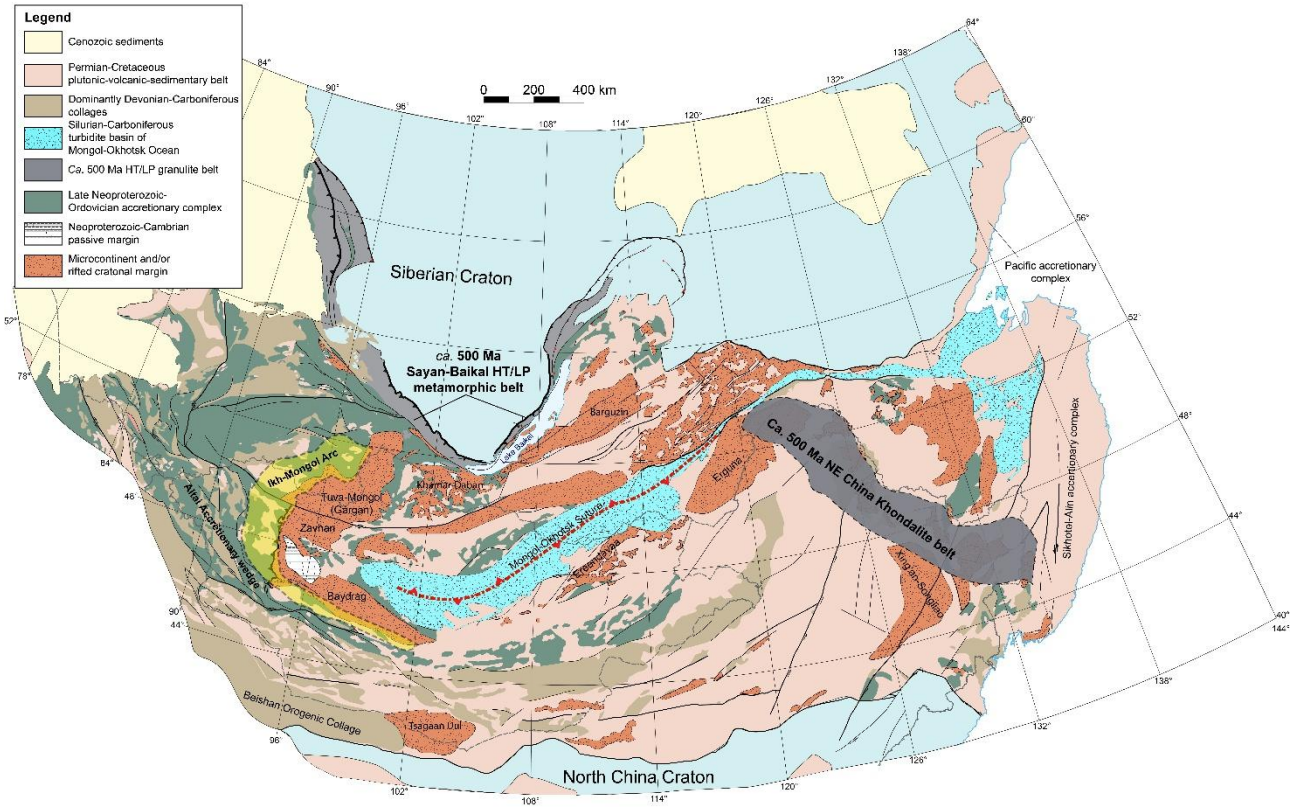


Figure 1: Simplified tectonic map of the eastern CAOB showing spatial distribution of the Altai accretionary system including the Ikh-Mongol magmatic arc system (highlighted) and the Altai accretionary wedge.

Structural-metamorphic studies across the Chinese Altai characterize a main tectono-metamorphic cycle that was connected with Silurian–Devonian suprasubduction dynamics characterized by a crustal

thickening phase associated with burial (D1B), followed by a Middle Devonian extension phase and crustal melting (D1M), and a Late Devonian shortening phase (D2) (Y. Jiang et al., 2022;Y. D. Jiang et al., 2019; Kong et al., 2022). Combined with regional structural-metamorphic data, cycles of extensional and contractional tectonic regimes can be defined, which also show eastward migration along-strike of the Altai range. Additional evidence comes from the Bidz ophiolitic terrane at the junction between the Chinese-Mongolian Altai and East Junggar domains, which comprises backarc-basin basalts and calc-alkaline andesites; zircon U–Pb dating yields ca. 350 Ma, indicating early Carboniferous backarc opening (Ma et al., 2026).This basin, together with the Erqis backarc, formed a southward-retreating marginal sea-arc system, with eastward propagation of extension mirroring slab rollback. Collectively, these records indicate that cyclic subduction advance-retreat controlled upper-plate contraction-extension switches, governing the spatiotemporal coupling of magmatism, metamorphism and sedimentation, in particular, extension during rollback enhanced arc magmatism, opened backarc or intracontinental rift basins, and triggered high-T/low-P metamorphism and widespread anatexis.

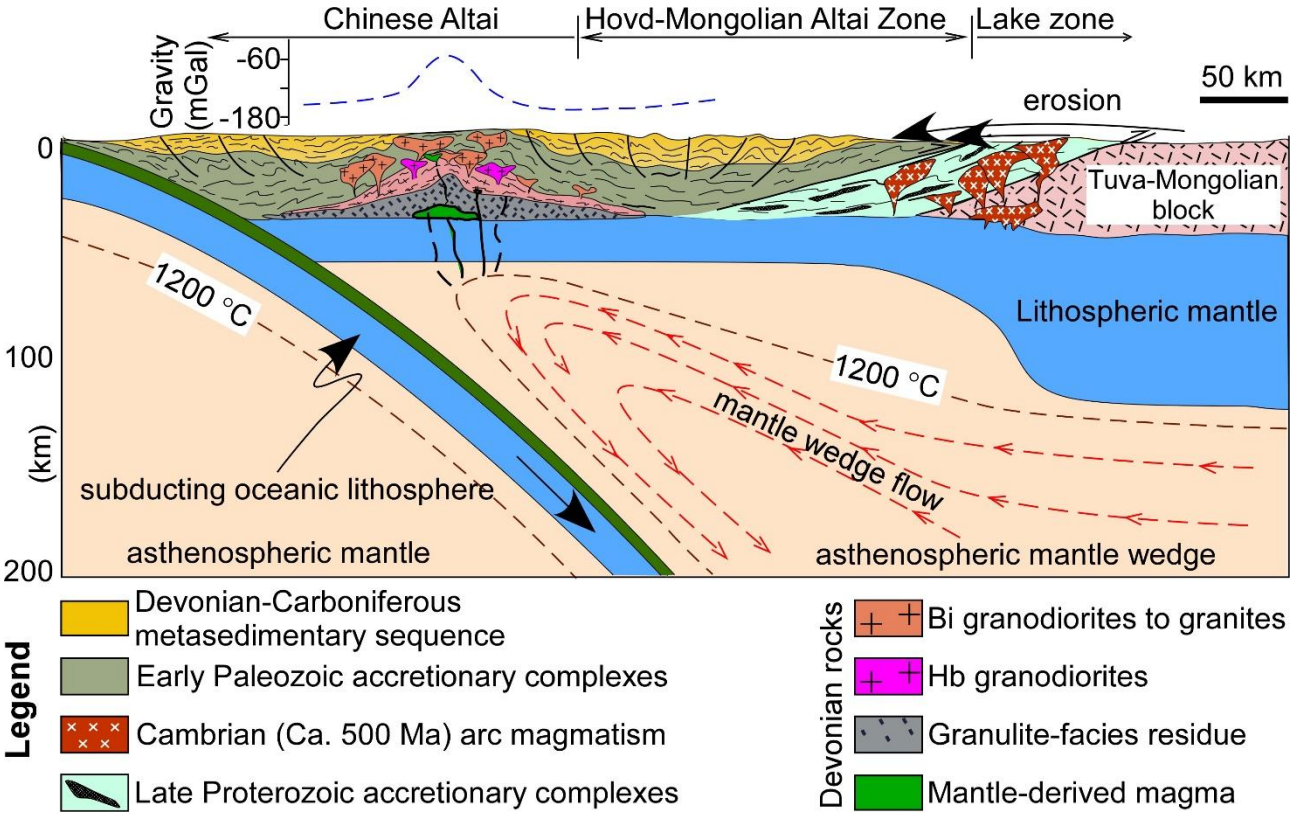


Figure 2:Tectonic interpretation for the generation of voluminous Silurian-Devonian granitoids and the formation of differentiated crust in the Chinese Altai. Idealized gravity profile on the Chinese Altai and Hovd-Mongolian Altai regions shows nature of gravity anomalies related to deep structure of partially molten wedge.

The Middle Devonian extension led to widespread crustal anatexis, producing a large amount of magma (Y. D. Jiang et al., 2016).This is in accordance with the fact close geochemical similarities were observed between the molten wedge sediments and voluminous Silurian–Devonian granitoids, implying genetic link.The molten orogenic lower crust was vertically extruded in the cores of regional F2 antiforms, probably assisted by the interplay between D2 horizontal shortening and magma diapirism (Wang et al.,

2021). Such process could have left a high-density garnet- and/or garnet–pyroxene granulite residue in the deep crust, which can be the major reason for the gravity high over the Chinese Altai. This crustal process hence further facilitated the differentiation of the accretionary wedge into a stable and mature continental crust in the Chinese Altai (Figure 2, (Y. D. Jiang et al., 2016)). This may be a key mechanism contributing to the peripheral continental growth worldwide.

Collectively, our results demonstrate that alternating subduction advance and retreat not only governed tectonic switches but also promoted anatexis, melt migration and crustal differentiation. This process, documented here for the Altai, may represent a fundamental mechanism for continental crust maturation in accretionary orogens worldwide, offering a new perspective on peripheral continental growth.

Acknowledgments

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Oroclines in the Central Asian Orogenic Belt: ATale of Deep Processes and Surface Response

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Keywords: Central Asian Orogenic Belt, Orocline, Geodynamics, Mountain building, Climate change

The Central Asian Orogenic Belt (CAOB) is characterized by a series of tight oroclines, yet the deep geodynamic processes that drove such large-scale bending remain enigmatic. Here, we apply recently developed crustal thickness proxies to reconstruct the trench migration histories around these oroclines. Combined with published geological and geophysical data, these reconstructions allow us to constrain the geodynamic origin of the oroclines. Our results highlight that both trench retreat and rotation of the overriding plate played crucial roles in oroclinal bending of the CAOB. Furthermore, the bending of the supra-subduction systems may have contributed to large-scale mountain building around the oroclinal hinges, which in turn could have influenced regional climate through rain-shadow effects.

Evolution of the Mongol-Okhotsk Ocean: Constraints from paleomagnetism

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Keywords: Mongol-Okhotsk Ocean, Mesozoic, initial closure, final closure, paleomagnetism

The Mesozoic evolution of the Mongol-Okhotsk Ocean (MOO) has significantly affected the configuration of the modern Asian continent. Although a scissor-like closure of the MOO has long been proposed, when and how the MOO closed are still hotly debated, especially the timing of initial closure of the MOO in its western segment, hindering our understanding of both the evolution of the MOO and tectonics of the northern Asian continent. In order to uncover the timing of initial closure of the MOO, we performed a multidisciplinary study in sedimentology, detrital zircon U-Pb dating and paleomagnetic on the LateTriassic clastic strata from the western segment of the Mongol-Okhotsk Suture.The upper Triassic strata on both sides of the suture were dominated by plant fossil-bearing alluvial-fluvial facies sediments, which unconformably overlain pre-Triassic geological units, indicating a terrestrial setting after the closure of the MOO. Detrital zircon U-Pb dating results revealed consistent age distribution patterns for samples from both sides of the suture with a predominant peak at ~253-251 Ma and a secondary peak at ~359-357 Ma, representing two main arc magmatic events during the bidirectional subduction of the MOO in the Late Devonian-Early Carboniferous and Late Permian-Early Triassic. Coeval LateTriassic paleomagnetic poles were obtained from the northern AMB andTarvagatay Block, revealing a comparable paleolatitude of the AMB (~31-33°) andTarvagatay Block (~32-34°) in the Late Triassic, arguing for that the western segment of the MOO should have closed at the LateTriassic.The compilation of sedimentology, detrital zircon U-Pb dating, magmatic and paleomagnetic evidence provides integrated constraints on the LateTriassic initial closure of the MOO in its western segment.To constrain age of final closure of the MOO in its eastern segment, we performed paleomagnetic study on the Upper Jurassic sedimentary rocks from the northern part of the Amuria Block (AMB) in northeastern China, south of the Mongol-Okhotsk suture Site-mean directions isolated from 21 sites show antipodal normal and reversed polarities, passing both fold and reversal tests. After applying Elongation/Inclination correction of inclination shallowing, an age-mean direction is calculated at D_s/I_s = 196.7°/-68.2° (k = 71.9, α_{95s} = 1.3°) in stratigraphic coordinates, corresponding to a Late Jurassic paleomagnetic pole of λ/ϕ = 78.3°N/184.6°E (A_{95} = 2.0°) for the AMB. Combining paleomagnetic data with regional geological evidence, we propose a possible Late Jurassic closure of the MOO in its eastern segment, marking the final closure of the MOO and the formation of the central Asian continent.

Architecture of the Mongolian Orocline and its geodynamic evolution

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Keywords: Orocline, suture, crustal structures, potential field analysis, geodynamics

The tectonic architecture and origin of the Mongolian Collage remain debated, particularly with respect to the significance of its lithospheric-scale orocline-like geometry and the distribution of sutures within the Mongolian Collage of the Central Asian Orogenic Belt (Kríža et al., 2021; Schulmann et al., 2023). By integrating geological observations, a synthesis of high-pressure metamorphic and arc-related magmatic rocks with magnetic and gravity datasets, we investigate the deep structure and tectonic evolution of this large-scale curvature. Multiscale edge detection applied to potential field data (Archibald et al., 1999; Vallée et al., 2004) reveals systematic lineament patterns and contact geometries across the continental and oceanic domains, defining a distinct U-shaped structure. This geometry corresponds to a belt of high-amplitude magnetic and gravity anomalies associated with Precambrian continental blocks surrounding the Mongol-Okhotsk sedimentary units interpreted as Silurian-Carboniferous oceanic domain. The distribution and orientation of geophysical fabrics display systematic changes in strike and dip across the northern limb, hinge, and southern limb of the "oroclinal bend", consistent with large-scale lithospheric curvature accompanied by sub-horizontal shortening. Magnetic and gravity data analyses indicate that some tectonic contacts extend to depths of ~40 km, suggesting that these discontinuities penetrate the entire crust and possibly part of the lithospheric mantle.

In contrast to previous models invoking multiple sutures separating the Precambrian microcontinents (Khain et al., 2002; Kuzmichev et al., 2005), our combined geological and geophysical analysis reveals no clear suture-related signatures between these blocks. Instead, they appear to form a semi-continuous chain of continental crust. The distribution of high-pressure metamorphic rocks and arc-related magmatic complexes (e.g. Štípská et al., 2010; Shatsky et al., 2015; Janoušek et al., 2018; Zhu et al., 2023) outlines two external continental scale sutures (the Mongol–West Sayan and Baikal–Sayan sutures) located along the western and southern parts of the outer margin of the bend together with an internal suture zone marking the northern boundary of the Mongol-Okhotsk domain. These observations support a model in which the continental domains bordering the western and southern margins of the Mongol–Okhotsk Ocean underwent large-scale lithospheric rotation during the late Paleozoic–Mesozoic, producing the present-day oroclinal geometry. In this interpretation, the continental blocks currently exposed along the northern margin of the Mongol–Okhotsk domain were likely already attached to the southern margin of the Siberian continent prior to the oroclinal bending event, although the nature of this attachment and their original orientation relative to Siberia remain uncertain.

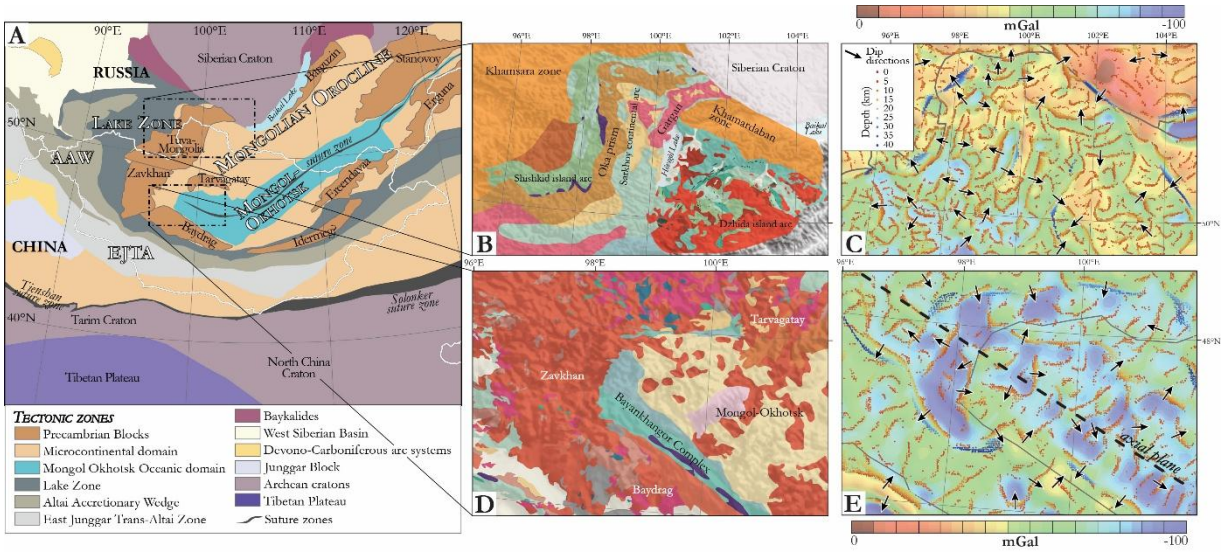


Figure 1. A. Global tectonic map of Central Asia and the Mongolian Collage (modified from Parfenov et al., 2003). B. Geological map of north of theTuva-Mongol Precambrian block. C. Isostatic residual gravity map and multiscale edge results. D. Geological map of the hinge of the Mongolian Orocline including the Mongol-Okhotsk oceanic domain, the Baydrag, Zavkhan andTarvagatay Precambrian blocks. E. Isostatic residual gravity map and multiscale edge results.

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The Hangai Dome in central Mongolia: A geophysical and geochemical perspective on the origin of intraplate basaltic volcanism

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Keywords: Hangai1, intraplate basaltic volcanism2, pyroxenite3

The Hangai Ridge in central Mongolia is an elevated intracontinental plateau and is considered a rigid Precambrian crustal block bounded by major long-lived faults (Cunningham, 2001; Calais et al., 2003). The region is characterized by scattered basaltic intraplate volcanism (Barry et al., 2003;Yarmolyuk et al., 2015; Papadopoulou et al., 2024), which is thought to coincide in time with the onset of block uplift (Walker et al., 2007), suggesting a possible link between these processes.

According to geophysical data, the crustal thickness beneath the Hangai Ridge reaches up to 60 km relative to the surrounding blocks, whereas to the east of the Hangai Dome it is thinner, with estimated values of ~42–44 km (Zorin, 1999; Zorin et al., 2002; Feng, 2021; He et al., 2016). Magnetotelluric studies beneath the Hangai block have revealed a heterogeneous zone of low electrical resistivity (20–80 Ω·m) in the lower crust (Comeau et al., 2018).These low-resistivity anomalies are spatially associated with surface manifestations of volcanism and are confined to the boundaries of the Hangai block. Low-velocity anomalies identified by seismic tomography beneath the Moho have also been interpreted as zones of partial melting (Petit et al., 2002; Feng, 2021). Observed low S-wave velocity (Vs) anomalies at a depth of 75 km are estimated to indicate the possible presence of melt, comprising ~4–7% (Jiang et al., 2026). Based on the obtained geophysical and geochemical data, several models have been proposed for the formation of volcanic melts: a deep-seated mechanism involving plumes of various natures and depths of origin (Zorin et al., 1990; Windley, Allen, 1993; Zorin, 1999); melting associated with lithospheric mantle delamination (Huang, Zhao, 2022; Xu et al., 2025); melting related to stratification of the lithospheric mantle at the boundary with the asthenosphere (Zhao et al., 2006;Tiberi et al., 2008; Huang & Zhao, 2022; Vinnik et al., 2024; Xu et al., 2025); and decompression melting associated with block uplift (Comeau et al., 2018; Papadopoulou et al., 2024). Based on elemental and isotopic data for the Hangai basalts, the primary melting source is considered to be peridotitic mantle (Yarmolyuk et al., 2015; Ivanov et al., 2015; Barry et al., 2003; Cunningham, 2001). In turn, explaining the enriched (radiogenic) isotopic signatures and trace element composition of the basalts requires the involvement of garnet-pyroxenitic rocks, the nature of which is proposed differently by various researchers.The introduction of enriched material into the melting region could occur either through plume involvement (Windley, Allen, 1993) or through ancient blocks entrained at mantle depths as a result of the geodynamic evolution of Central Asia (Savatenkov et al., 2015; Sheldrick et al., 2020). Given the ambiguities in geophysical interpretations, the decisive argument in choosing between models becomes the geochemical characteristics of the basalts, which reflect the composition and melting conditions of the mantle source.

Based on a comparison of experimental melts from peridotites, pyroxenites, and carbonatized analogues with the composition of natural basalts, it has been established that a peridotitic source cannot generate melts with the observed characteristics. Experimental data show that peridotite melting at pressures corresponding to depths of 70–100 km produces melts with higher Mg# (>65) and lower TiO_2 contents (<2 wt.%) at comparable degrees of melting (Herzberg, 2011). In contrast, pyroxenite melting (including carbonatized varieties) at the same pressures produces melts with high TiO_2 contents

(up to 3–4 wt.%) and low Mg# (<60) (Lambart et al., 2016). The discrimination between melts from different sources is clearly observed using the geochemical parameter FCMSKANT, based on the behavior of a suite of petrogenic oxides ($FeO–CaO–MgO–SiO_2–K_2O–Al_2O_3–Na_2O–TiO_2$) (Yang et al., 2019), where the FCMSKANT value for pyroxenite-derived melts exceeds 0.2, and for peridotite-derived melts it is below 0.2. This fundamental difference is due to the fact that pyroxenites are enriched in FeO, TiO_2, and incompatible elements compared to peridotites, and their melting does not require high degrees of partial melting to produce enriched melts. Late Cenozoic basalts of the Hangai are characterized by elevated TiO_2 contents (typically >2.5–3.0 wt.%), low Mg# values (typically <60–65), enrichment in incompatible elements (Barry et al., 2003; Yarmolyuk et al., 2015; Savatenkov et al., 2015; Sheldrick et al., 2020; Papadopoulou et al., 2024), and FCMSKANT values >0.4. These features indicate the influence of differentiation processes on the magmas or melting involving an enriched pyroxenite source.

Thus, the prevailing model of upper mantle melting involving a peridotitic source fails to explain the observed geochemical characteristics of the Hangai Dome basalts. The formation of magmas from pyroxenites indicates that melting occurred in the lithospheric mantle without significant involvement of a peridotitic source. This is consistent with delamination and/or stratification models, in which enriched mafic (pyroxenitic) layers of the lithosphere are involved in melting, rather than only asthenospheric peridotite.

Acknowledgments

The study was supported by Russian Science Foundation Grant No. 25-77-30006, https://rscf.ru/project/25-77-30006.

Using zircon (U-Th)/He thermochronometry to investigate the growth and collapse of the Mongol-Okhotsk Orogenic Belt

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Keywords: Zircon(U-Th)/He, Mongol-Okhotsk Orogenic Belt, exhumation, extensional collapse

The exhumation record preserved in collisional belts is key to quantifying orogenic processes during continental assembly and assessing the influence of collisional inheritance during later continental dispersal. In central Asia, the closure of the Mongol-Okhotsk Ocean and the growth of the Mongol-Okhotsk Orogenic Belt (MOOB) marked the final assembly of the Central Asian Accretionary Belt, the largest accretionary orogen on Earth (e.g., Xiao et al., 2018). Data constraining the magnitude of the collisional orogeny, however, are limited and variable. In central Mongolia, this orogeny has been considered 1) short-lived but significant extending into northern China (Jurassic collision; Yang et al., 2015); 2) "weak" possibly associated with strike-slip deformation without significant crustal thickening and topographic building, consistent with limited Jurassic-Cretaceous exhumation in central Mongolia (Jolivet et al., 2017) and 3) strong enough to create a topographic uplift that inverted the regional drainage in southern Russia (Arzhannikova et al., 2020). Its Late Mesozoic extensional collapse is part of a large intraplate rift system that extends through eastern Asia to the Pacific Plate. Even though the main driver for the continental-scale rift is associated with slab roll-back of the Pacific Plate, the rift system that pulled apart the MOOB is considered a wide-rift driven by gravitational instability of an overthickened crust (e.g., Meng et al., 2022), which suggests that the preceding orogeny was strong enough to overthicken the crust and influence the intraplate rift.

This study is motivated by three questions for central Mongolia: 1) When did the orogen experience cooling driven by erosion and exhumation during the collision? 2) What is the exhumation signature (timing and magnitude) across the orogen related to the extensional event? and 3) How might the collisional orogeny have influenced the subsequent intraplate rifting in central Mongolia? To address these questions, we investigated regional patterns of cooling north of the Mongol-Okhotsk suture zone (Fig. 1).

We present new zircon (U–Th)/He (ZHe) data collected in two domains north of the Mongol Okhotsk Suture Zone (Fig. 1): an inner or proximal domain composed of Paleozoic accretionary complex deformed mainly by dip-slip structures parallel to the orogen, and an outer or distal domain composed of Precambrian to Triassic units deformed by strike-slip deformation parallel to the orogen. These two domains sit between Cretaceous metamorphic core complexes (MCC) that document localized NW-SE ultraextension (e.g., Daoudene et al., 2017). By comparing the cooling record from proximal and distal regions relative to the suture zone, this study aims to identify cooling patterns, assess thermal histories, and quantify erosion and exhumation histories, possibly driven by deformation across the MOOB.

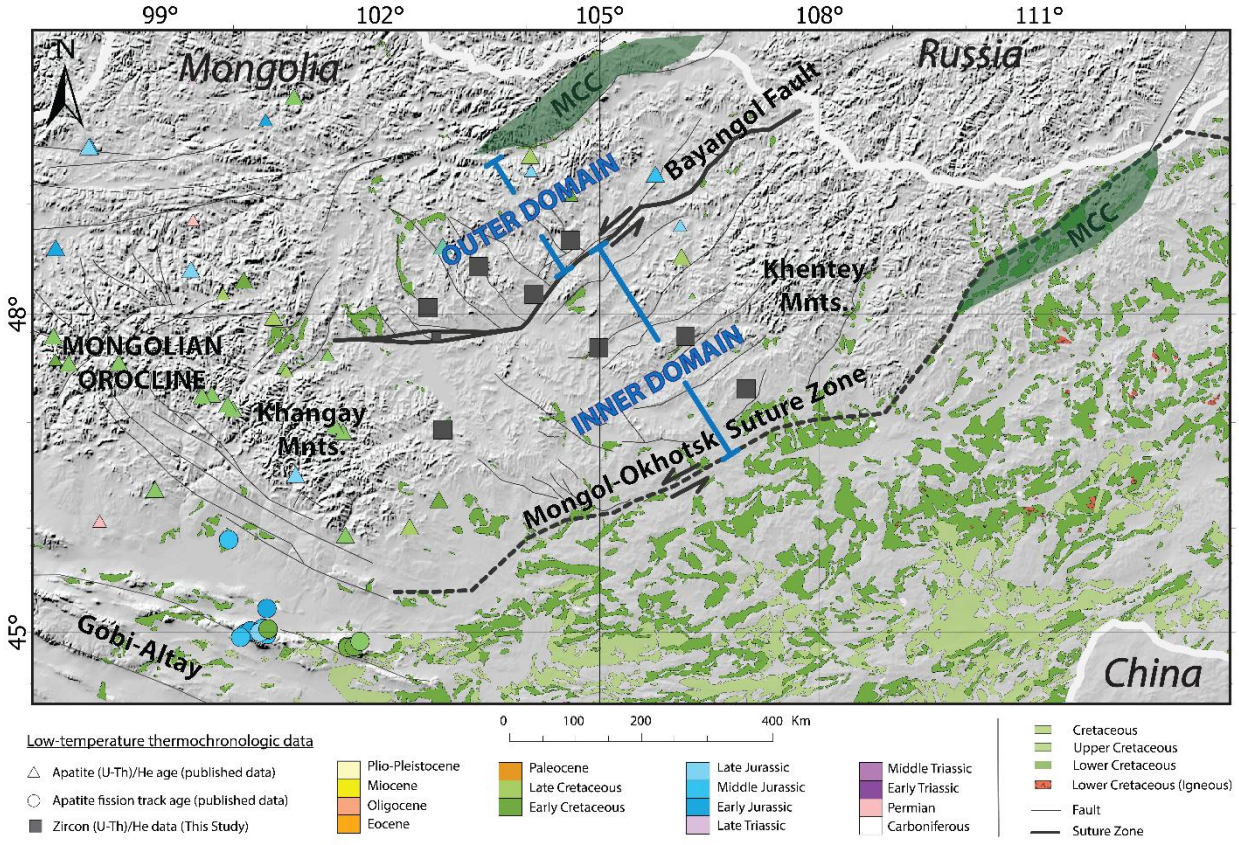


Figure 1. Simplified map showing the main features of the Mongol-Okhotsk Orogenic Belt, Cretaceous depocenters and metamorphic core complexes, and the distribution of samples across the inner and outer domains. Published cooling data compiled by Jepson et al. (2021).

Preliminary results indicate that the outer domain records rapid cooling through the ZHe partial-retention zone during the Late Jurassic and Paleozoic, whereas the inner domain records rapid Early Cretaceous cooling. Since magmatism had largely migrated from central Mongolia by the mid-Jurassic (e.g., Wang et al., 2021), we interpreted the cooling record to reflect regional changes in the geothermal gradient and erosion due to exhumation. The Late Jurassic ZHe ages in the outer domain are interpreted to record and constrain the amount of exhumation in the hanging wall of thrust faults within orogen-parallel shear zones during the collision. At the same time, the Paleozoic ZHe ages suggest that exhumation during the collision was variable in the exterior part of the orogen. The Early Cretaceous cooling in the inner domain, the core of the orogen, is interpreted as exhumation during the extensional collapse of the orogen. Considering that the Cretaceous cooling signature in the outer domain is recorded by apatite fission track ages (Henriquez et al., 2023), our results suggest that the distal part of the orogen experienced less cooling and less exhumation compared to its core.

The regional Cretaceous cooling signature identified for central Mongolia is consistent with the regional unconformities (e.g., Tully et al., 2024), and the preservation of Cretaceous basins south of the suture zone and Cretaceous-Paleocene peneplain surfaces north of the suture zone within the inner and outer domains (e.g., Khukhuudei et al., 2024). Thus, our results suggest that the collapse was not only asymmetric with respect to the suture zone, with enhanced exhumation across the northern side, but also variable. Considering the enhanced exhumation on the northern side, we speculate that the

differences in erosion and exhumation between the two areas between the MCCs (Fig. 1) may have been driven by increased shortening and crustal thickening within the core of the orogen.

Acknowledgments

This research was supported by the National Science Foundation through EAR-Tectonics 1917645, Collaborative Research: Suturing the hearth of Asia:Tectonics of the Mongol-Okhotsk Ocean Closure, the AGeS-Dig program that funded the project "Mentoring and training undergraduate students in thermochronology by investigating the cooling record of the collapse of the Mongol-Okhotsk Belt" (NSF EAR-1759200,-1759353,-1759201), and California State University San Bernardino.

Extra-prolate metamorphic core complexes of the Mongol–Okhotsk orogenic belt: Insights from Ereendavaa & Buteel

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Keywords: Mongol-Okhotsk, Metamorphic Core Complex, Central Asian Orogenic Belt

Metamorphic core complexes (MCCs) are common tectonic features of post-orogenic extension that provide insight into the mechanisms of crustal collapse and continental evolution (Coney, 1980). Numerous Early Cretaceous (~135–110 Ma) MCCs are widespread across eastern Asia (Zorin, 1999; Donskaya et al., 2008; Wang et al., 2011; Daoudene et al., 2013; Miao et al., 2017) Asian MCCs are commonly classified as "Cordilleran-type" because they share the first-order structural architecture of classical MCCs. However, a subset that exhumed through the Mongol–Okhotsk accretion belt differs fundamentally in second-order traits like aspect ratio, population density, and patterned alignment (Fig. 1, magenta). These MCCs exhibit remarkably prolate plan-view geometries, close spatial clustering, and systematic alignment with inherited accretionary fabrics.

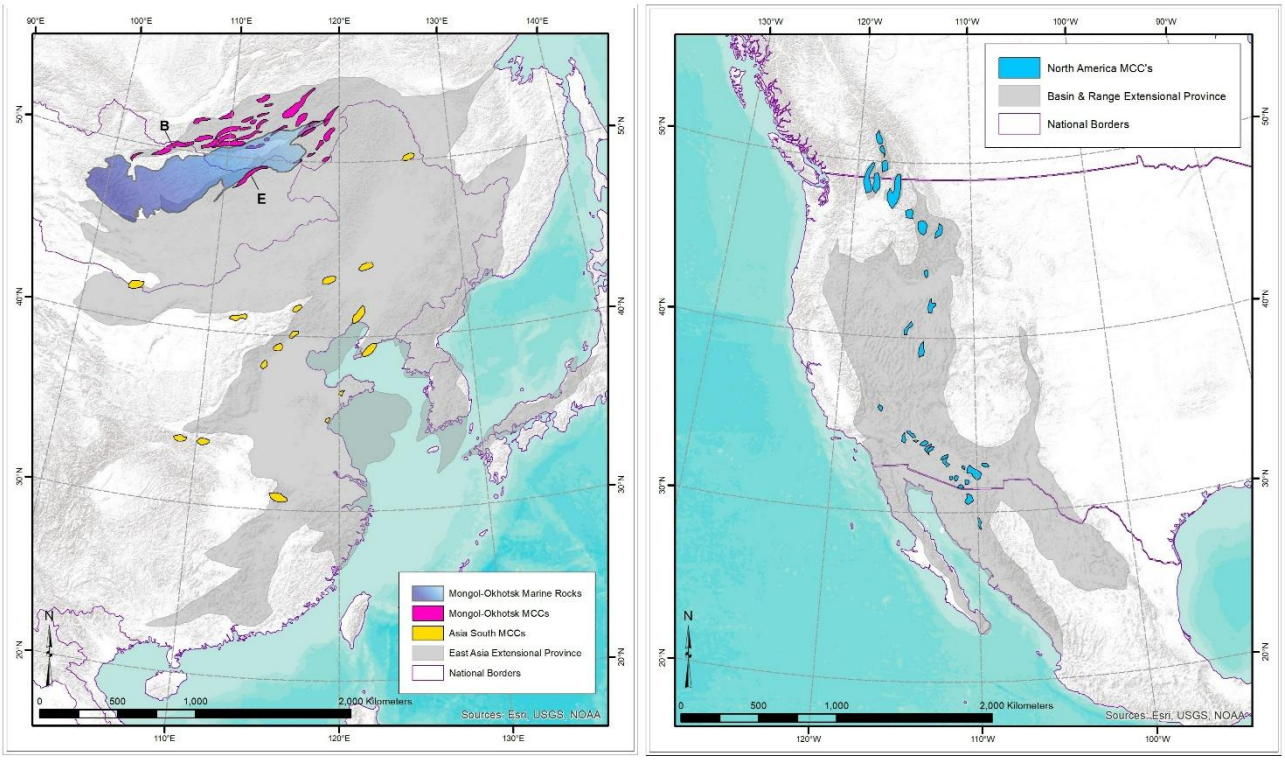


Figure 1. Same-scale comparison of Asian and Cordilleran MCCs and their respective intra-continental extensional provinces. Mongol-Okhotsk MCCs modified after (Zorin et al, 1999), Asia South MCCs after (Wang et al., 2011), Cordilleran MCCs after (Whitney et al., 2013).

We investigated the Ereendavaa and Buteel metamorphic core complexes using integrated field structural mapping, microstructural analysis, and $^{40}Ar/^{39}Ar$ geochronology to constrain their geometry,

timing, kinematics, and relationship to inherited accretionary terranes. Combined with regional structural compilations and cross sections, these data constrain the full extents, demonstrate the influence of inherited tectonic fabrics on MCC development, and form a basis of comparison for North Asian MCCs with south Asian and Cordilleran families.

The two MCCs preserve contrasting kinematic histories. Buteel exhibits a classical metamorphic core complex geometry, with rotated foliations on opposing flanks and well-clustered antipodal stretching lineations consistent with rolling-hinge exhumation (Bartley and Fletcher, 1990). Ereendavaa, in contrast, is characterized by strongly asymmetric fabrics, northwest-dipping foliations across both flanks and the crest, sparse southeast-dipping fabrics, and dispersed stretching lineations confined to a common northwest-dipping foliation orientation. Rather than recording wholesale rolling-hinge rotation, deformation at Ereendavaa appears to reflect kinematic reversal of inherited contractional fault architecture.

New $^{40}Ar/^{39}Ar$ deformation ages from the upper plate rocks of Ereendavaa, composed of the old accretion complex formed during Mongol-Okhotsk closure, show that contractional deformation persisted into at least the Early Jurassic before regional extension commenced only a few tens of millions of years later.

New $^{40}Ar/^{39}Ar$ ages from the MCC detachment faults and metamorphic cores corroborate previously reported Early Cretaceous exhumation ages for both MCCs while demonstrating exhumation over substantially greater distances than previously constrained. These ages support the regional extents mapped by Mongolian geologists (Tomurtogoo et al. in: Petrov et al., 2014) and indicate coeval exhumation along the full lengths of both MCCs. With each MCC located on opposite margins of the orogenic belt, their opposed detachment polarities and hanging-wall vergence are consistent with purported gravitational collapse of the tectonically thickened Mongol-Okhotsk orogen (Graham et al., 2001).

We propose that exhumation of Mongol–Okhotsk MCCs were able to propagate far along strike and formed a patterned cluster by exploiting a recently amalgamated, mechanically anisotropic accretionary orogen that was thermally weakened along discrete corridors by slab breakoff (Van Der Voo et al., 2015) beneath the margins of the double-sided Mongol–Okhotsk subduction system. This tectonic setting differs fundamentally from that of age-equivalent south Asian and classical Cordilleran MCCs, which developed within more mature crust above more diffuse thermal systems.

Acknowledgments

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III. Basin Analysis and Stratigraphy

International Continental Scientific Drilling Project of the Songliao Basin: Terrestrial Geological Records of the Cretaceous Dinosaur Age

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Keywords: International Continental Scientific Drilling Program (ICDP); Songliao Basin; Cretaceous; paleoclimate; chronostratigraphic framework;

Over the past century, the global climate system has undergone sustained warming. Continued anthropogenic warming may drive the Earth system toward greenhous climate conditions comparable to those recorded during greenhouse intervals in Earth's geological past. The Cretaceous is widely regarded as a representative greenhouse interval and provides valuable analogues for understanding greenhouse climate dynamics and constraining future climate projections (Tierney et al., 2020;Wang et al., 2024). It was characterized by elevated atmospheric CO_2 concentrations, high global temperatures, reduced continental ice volume, and high sea levels. During some intervals of the Cretaceous, atmospheric CO_2 concentrations may have been four to ten times higher than pre-industrial levels, while global mean sea level may have stood 100–200 m above the present level (Miller et al., 2005). However, previous research has focused predominantly on marine records, leaving terrestrial climate variability less well understood because of the scarcity of continuous continental archives.

During the Cretaceous, the Songliao Basin was located along the eastern Asian continental margin and evolved into one of the world's largest continental lacustrine basins, although it was intermittently affected by marine incursions. Its thick and exceptionally continuous sedimentary succession provides an ideal archive for investigating terrestrial climatic and environmental change (Wang et al., 2013). The ICDP Songliao Basin project was the first continental scientific drilling project to recover cores from a nearly complete Cretaceous continental succession (Gao et al., 2019).

By 2021, the project had completed the SK-1, SK-2, and SK-3 drilling campaigns, recovering approximately 8,187 m of core with an overall recovery rate of 97.03% (Wang et al., 2013; Gao et al., 2019). Together, these cores constitute a nearly continuous composite record and have supported research on terrestrial paleoclimate, paleoenvironmental change, major geological events, source-rock development, biotic turnover, and rapid climate change. They have also provided scientific support for hydrocarbon exploration in the Daqing Oilfield (Gao et al., 2019). Geochronological studies established a high-precision continental Cretaceous chronostratigraphic framework, with local age resolution reaching approximately 100 kyr (Liu et al., 2020; Wang et al., 2024).

Core-based studies have identified climatic variability on million-year, orbital, millennial, and possibly annual timescales (Huang et al., 2021). These studies have also revealed terrestrial responses to major geological events and suggested that variations in terrestrial water storage may have contributed to Cretaceous sea-level fluctuations (Wang et al., 2013; Gao et al., 2021). Episodes of marine incursion promoted water-column stratification and organic-carbon enrichment (Gu et al., 2022). Overall, the

project has substantially advanced our understanding of terrestrial processes under greenhouse conditions and provided valuable geological constraints for projections of future climate change (Wang et al., 2013; Gao et al., 2019;Tierney et al., 2020).

Acknowledgments

We would like to express our gratitude to theInternational Continental Scientific Drilling Pro-gram (ICDP), the Ministry of Science andTech-nology of China, the China Geological Survey ofthe Ministry of Natural Resources of China, theNational Natural Science Foundation of China,PetroChina Daqing Oilfield and Jilin Oilfield fortheir continuous support of the InternationalContinental Scientific Drilling Project of theSongliao Basin.

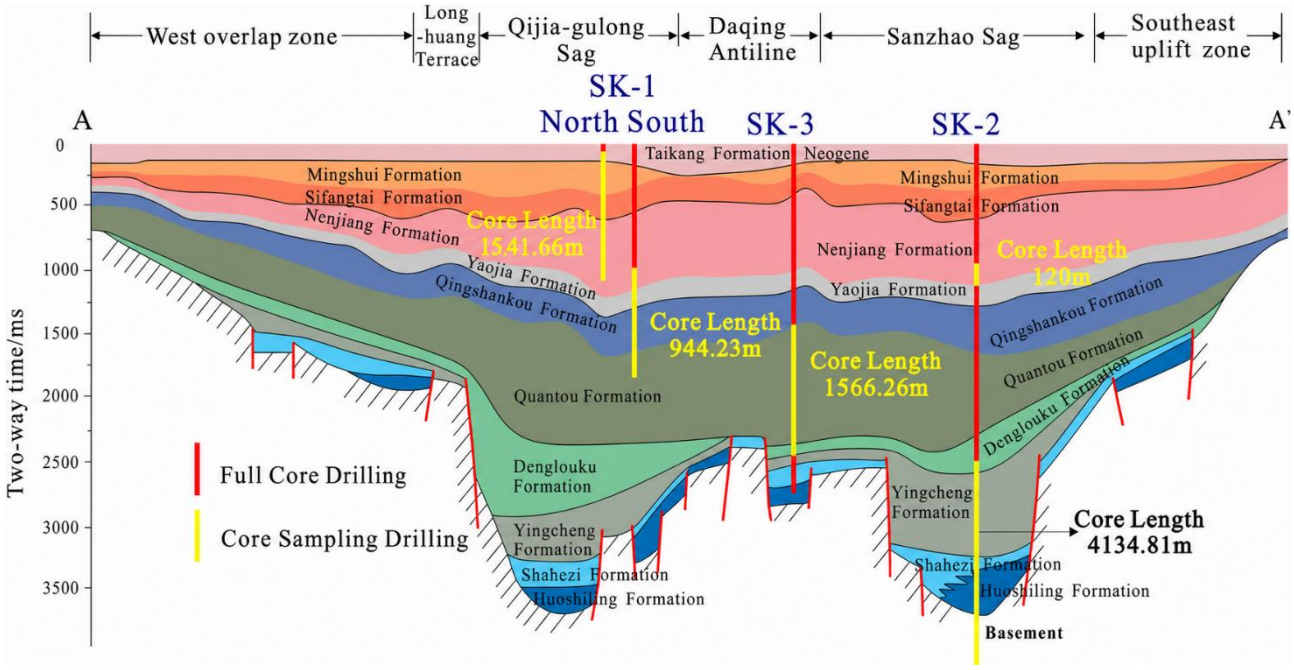


Figure 1. Profile of the Songliao Basin and the location of the "Three Wells and Four Drilholes" of the International Continental Scientific Drilling Project of the Songliao Basin after (Feng et al., 2010).

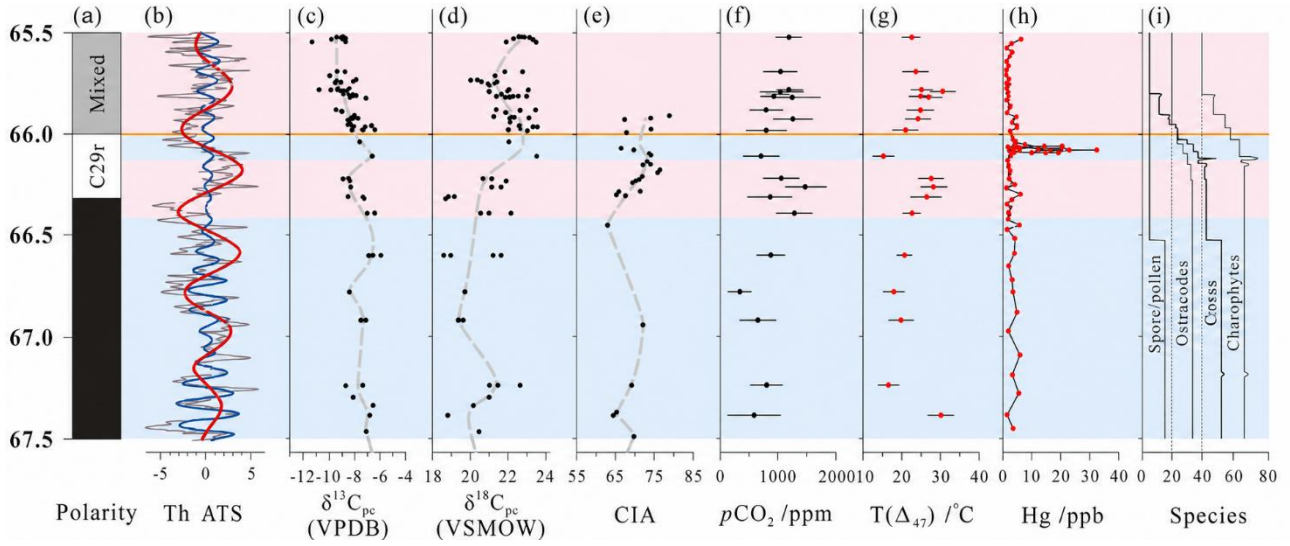


Figure 2. Climatic-environmental-biological records of the Songliao Basin before and after the K-Pg boundary, after (Zhang et al., 2018; Gao et al., 2021). (a) Magnetic stratigraphic column; (b) Cyclostratigraphic column (based onTh logging data); (c) Paleosol carbonate δ13C;(d) Paleosol carbonate δ18O; (e) Chemical Index of Alteration (CIA); (D pCO2; (g)Temperature; (h) Hg concentration: (i) Species

Cenozoic regional tectonics of Mongolia

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Keywords: Mongolia, intracontinental transpression, active faults, Cenozoic volcanism

Mongolia is one of the world's most significant site for studying Cenozoic intracontinental tectonics and provides valuable insights into the long-term geodynamic evolution of Eurasia. Despite extensive research, the primary mechanisms driving its intracontinental deformation remain debated. Here, we demonstrate that the Cenozoic tectonic evolution of Mongolia and its surrounding regions was primarily controlled by the combined influence of four major geodynamic processes: the India–Asia collision, extension associated with the Baikal Rift System, lithospheric and mantle dynamics beneath the Khangay Dome, and subduction of the Pacific Plate.

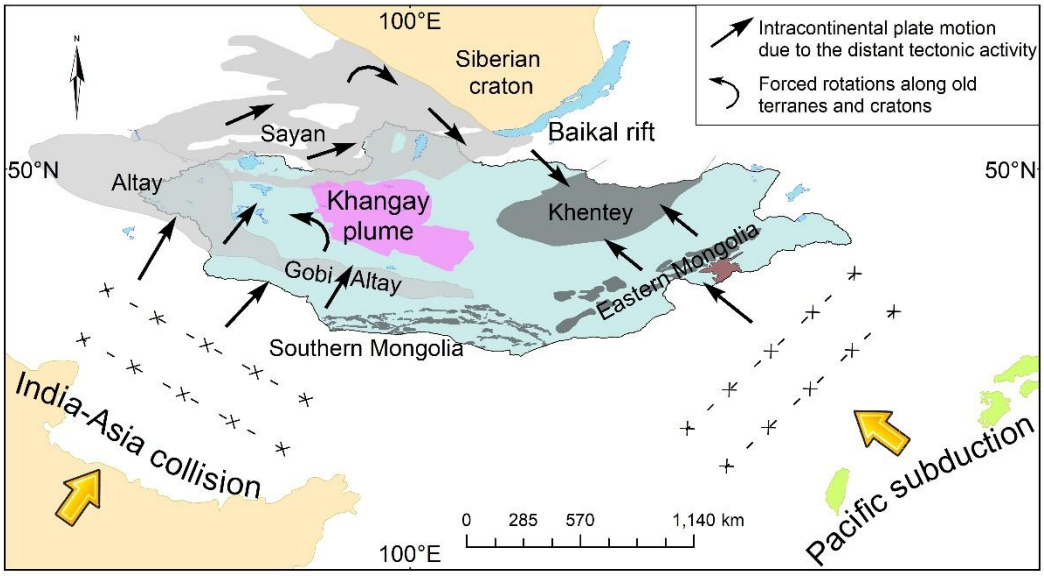


Figure 1. Map showing the relationships in Mongolia between distant tectonic activity and intraplate motion derived from GPS data. Black arrows indicate present-day plate motion. Dashed lines with crosses show long distance major tectonic activity towards Mongolia. Grey areas contain transpressional intracontinental mountain belts, and pink areas represent old terranes, cratons and microcontinents. Dull yellow arrow indicates motion direction since the Mesozoic.

The most informative areas for Cenozoic intracontinental tectonics in Mongolia are the Mongolian Altay, Gobi Altay, Khangay and Khuvsgul Mountains.

The Cenozoic structures of the Mongolian Altay, Gobi Altay, and other isolated mountain ranges in southern Mongolia, such as the GobiTianshan, are closely related to the India–Asia collision.These mountain ranges are generally interpreted to have formed at approximately 5–8 Ma as a result of far-field transpressional deformation associated with the ongoing continental collision.

The Khangay Mountains were uplifted above a deep, warm mantle upwelling that was spatially associated with partial melting at depths exceeding 80 km in the upper mantle. The widespread Cenozoic basaltic volcanism in the Khangay has commonly been attributed to lithospheric thinning. However, the present-day crust beneath the Khangay is approximately 55 km thick, suggesting that significant lithospheric thinning may not have been necessary to generate the observed magmatism.

The Khentey and the Orkhon–Selenge Mountains exhibit arch-shaped uplift and preserve extensive remnants of an ancient erosion surface. Their structural controls are fault systems that remain insufficiently investigated.

The Sayan–Khuvsgul mountainous region developed through interactions between collision-induced tectonic forces and the stable Siberian Craton. We propose that the Tannu-Ola Range in Tuva, together with the Tsagaan Shuvuut and Khan Khukhey ranges and the Uvs Basin in Mongolia, constitutes part of the South Sayan mountain system and formed by intraplate deformation driven by the far-field effects of the India–Asia collision.

Eastern Mongolia and the southeastern Gobi are characterized by fault-bounded Cenozoic basins that inherited their structural framework from earlier Mesozoic basins. During the Cenozoic, these regions experienced only modest uplift, which occurred more gradually than in western and central Mongolia.

Several geodynamic models have been proposed to explain the widespread Cenozoic volcanism in Mongolia. Among these, the volcanism of eastern Mongolia is most plausibly linked to subduction of the Pacific Plate, whereas the mechanisms responsible for volcanism in northern, central, and southern Mongolia remain poorly constrained and continue to be debated.

Tsakhiurtyn Hundi Lakeland and Khutul Usny Cave – geology, paleoenvironment, and early Homo sapiens (Arts Bogd, Mongolia)

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Tsakhiurtyn Hundi Lakeland

Research in the southern part of the Arts Bogd massif in the Gobi Altai and its adjacent areas (Fig. 1A) has refined existing knowledge of its geomorphology and Quaternary geology, and consequently, has enabled attempts to reconstruct the palaeoenvironmental conditions in which early hunter-gatherer communities operated (Masojć et al., 2024, 2025; Bobrowski et al., 2025). The research led to the identification of the Tsakhiurtyn Hundi Lakeland, located south of Arts Bogd, composed of 15 ephemeral, mostly endorheic playa lakes. Geomorphological and tectonic analyses have revealed that the genesis of the largest lakes is complex. Their development, lasting at least 140,000 years, was primarily influenced by basement tectonics associated. The studied lakes are located along the axis of the pull-apart Shereegiin Gashuun Basin developed between the Bogd Deforming Belt and the Gobi Tien-Shan Deforming Belt (Fig. 1B; Sikora et al., 2025). The Shereegiin Gashuun Basin is an endorheic basin with clearly visible Quaternary subsidence in the relief. The tectonic factor was superimposed on the erosive activity of westerly winds, the so-called Westerlies. These caused the formation of deflationary basins in tectonic depressions, where lake waters accumulated. Climatic factors during the Quaternary period caused significant changes in lacustrine sedimentation, and their record in many lakes is highly variable (Michalec et al., 2025; Sikora et al., 2026). The most frequently observed sediment variability is lacustrine, fluvial, and aeolian. These changes reflect regional and global climate trends and are dictated by the region's active tectonics, which uplifted the Gobi-Altai massif and rejuvenated the terrain relief. Tsakhiurtyn Hundi Lakeland was characterised by a somewhat different development than neighbouring areas, particularly the nearby Ulan Nuur Basin. This is because both areas are separated by hills that separate Tsakhiurtyn Hundi Lakeland from the east, whose uplift is associated with the Quaternary eastward thrust of the eastern edge of the Arts Bogd. Comparing the research results with those published for neighbouring areas indicates that Tsakhiurtyn Hundi Lakeland exhibited environmental characteristics intermediate between the Ulan Nuur Basin, the Valley of Gobi Lakes, and the southern Gobi during the Quaternary (Sikora et al., 2026). With further research, this area will provide valuable information that will complement our understanding of the development of relief and paleoenvironmental reconstructions in the northern Gobi region. This is important given the confirmed activity of early humans in this area, and in the longer term, for inferences about future climate change and the development of adaptation techniques to these changes.

Khutul Usny Cave

Research at Khutul Usny Cave (Fig. 1C), developed in Lower Cretaceous tarchybasalts in the Arts Bogd massif, also provides significant information about Quaternary geological events and environmental changes (Masojć et al., 2024). Numerous Palaeolithic tools, faunal remains, and a tooth dating to 28,000–31,000 years ago belonging to the species Homo sapiens were found in its sediments (Fig. 1D; Masojć et al., 2026). Furthermore, the accumulation of rock debris in the upper part of the cave sediment profile and the presence of rockfalls at the cave entrance, beneath which a fissure cave developed, suggest that the modern cave is part of a larger structure that existed during the Pleistocene.The collapse of its frontal section may be related to high seismic activity in the region. Furthermore, structural studies of the rock mass indicate progressive brittle deformation associated with slope tectonics. The development of cracks and fractures along existing tectonic discontinuities manifests this. A strong seismic event could probably cause further extensive damage to the slope where the cave is located and bury part of the Khutul Usny valley.This is a prime example of how dynamic geological factors influenced the functioning of prehistoric communities in Mongolia.

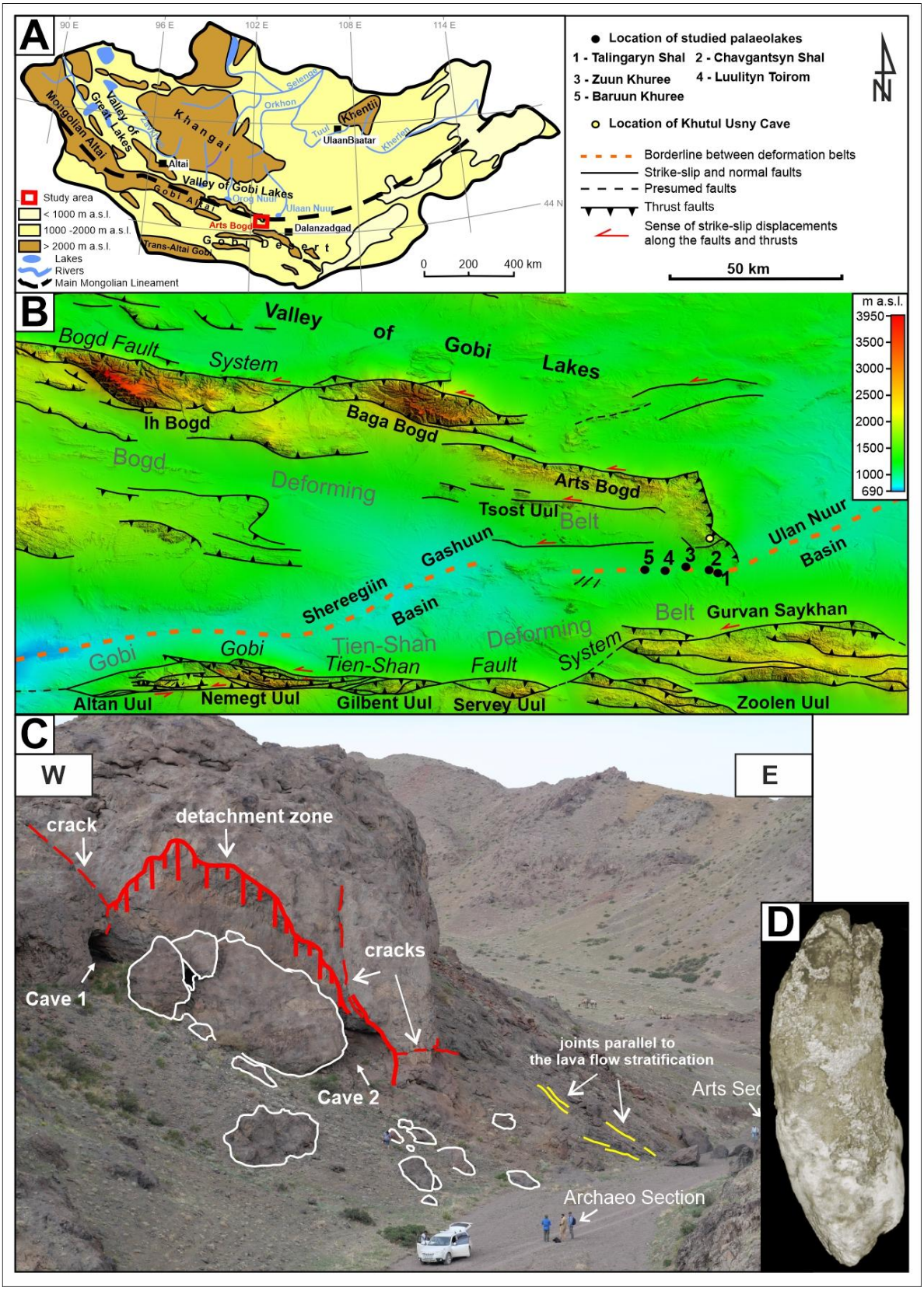


Fig. 1. A and B – Location of the study area on a sketch map of Mongolia and within the restraining bend structures of the Gobi Altai and Gurvan Saikhan ranges (after Sikora et al., 2025 and 2026). C – View on the Khutul Usny Cave with geomorphological and structural interpretation. D – A Late Pleistocene human tooth from Khutul Usny Cave (after Masojć et al., 2026).

Recent advances in Mongolian vertebrate paleontology and their implications for Cretaceous stratigraphy

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Keywords: dinosaurs, Cretaceous stratigraphy, Gobi Desert

Most Late Cretaceous dinosaurs from Mongolia have been collected in the south, where the Gobi Desert is situated.To date, more than 100 dinosaur species have been described from Mongolian Cretaceous sediments. Several dinosaur-bearing formations—including the Sainshand, Bayanshiree, Djadokhta, Baruungoyot, and Nemegt formations—are well known for their rich vertebrate assemblages. Sedimentological and paleontological data indicate that each formation records a distinctive ancient environment and vertebrate fauna. (Jerzykiewicz, 2000)

The Javkhlant Formation is restricted to a limited area of the eastern Gobi (Shuvalov, 1975), and its stratigraphic position remains debated (Eberth et al., 2009). A small thescelosaurid dinosaur, *Haya griva*, was discovered in the Javkhlant Formation of the eastern Gobi (ca. 100–70 Ma) (Makovicky et al., 2011). An identical fossil was later collected from coarse-grained red beds that underlie the Djadokhta Formation in the Nemegt Valley(Barta & Norell, 2021).

The Bayanshiree Formation is one of the most widely distributed Cretaceous units in Mongolia (Shuvalov, 1975).The SharTsav locality, recently designated as the country's first national-level geopark, exposes the Bayanshiree Formation and has yielded a small theropod, *Avimimus* sp., as well as sauropod remains (Watabe & Suzuki, 2000). *Avimimus* has otherwise been reported only from the Nemegt Formation (Kurzanov, 1981).

Recent studies support the following conclusions. Discoveries of the same vertebrate species across Mongolia suggest that some of these formations may have been deposited coevally. Although the vertebrate assemblages are similar, their depositional environments and modes of accumulation differ.

Hydroclimatic variability in northern Inner Asia over the past 2500 years inferred from varved sediments of Lake Shira (Chulym–Yenisei Basin, southern Siberia)

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Keywords: Varve chronology, Westerly moisture transport, Late Holocene hydroclimate

Lacustrine sediment archives are widely used to reconstruct Holocene climate and environmental change, with chronologies most commonly constrained by radiocarbon (^{14}C) dating of carbon-bearing materials. In the semi-arid and arid regions of Inner Asia, where open vegetation limits the input of short-lived terrestrial plant remains (e.g. leaves, seeds, needles) that yield the most reliable chronologies, bulk organic carbon is instead the material most commonly used for ^{14}C dating. However, dating bulk samples involves large uncertainties from possible ^{14}C reservoir effects, a well-recognized obstacle to building robust chronologies for many, if not most, Inner Asian lakes.

To obtain palaeoclimate proxy records for northern Inner Asia with a robust chronology, we studied a new core (Sh-II-1) from deep-water Lake Shira in the Chulym-Yenisei Basin of South Siberia (Fig. 1), previously reported as the first lake with annually laminated sediments in the region. Examination of a composite petrographic thin-section record yielded the first fully varve-based chronology for the upper 147 cm of the Lake Shira sediments. The well-preserved varves show properties of the endogenic and clastic-biogenic types and can be subdivided into four seasonal sublayers (winter–early spring, late spring, early summer and late summer–autumn). The sequence comprises 2491 varve years (-70–2420±40 a BP; 2020 CE–470±40 BCE) with a total counting error of only 1.6% (i.e. ±40 years). The chronology is independently supported by the ^{137}Cs record, which places the 1963 CE nuclear-testing peak and the onset of testing around 1954 CE at the expected depths (Fig. 1).

To test the reported ^{14}C reservoir effect in the lake, nine AMS ^{14}C dates on bulk organic sediment fractions were compared directly with the varve-based age-depth model. The reservoir effect varies significantly over the last 2500 years, ranging from 240±30 to 1045±30 years (Fig. 1). This challenges both the widely used modern calibration approach, where a time-invariant reservoir age is assumed, and interception-based regression approaches, either of which may introduce substantial dating errors. Where varved sediments or short-lived terrestrial plant macrofossils are unavailable, purified lignin phenols (obtained by liquid chromatography) or purified pollen concentrates should be prioritized as alternative ^{14}C dating materials.

Geochemical and mineralogical records from Sh-II-1 reveal a cyclical succession of multidecadal- to centennial-scale wet–dry intervals, showing that Lake Shira's depositional regime is highly sensitive to hydroclimatic change. Three pronounced arid phases, characterized by low lake levels, high salinity, strong authigenic carbonate formation and holomixis, are identified at 350–479 CE, 1459–1534 CE and 1898–1928 CE, coinciding with the Dark Ages Cold Period and the beginning/end of the Little Ice Age (LIA). A fourth, less intense dry phase (349–296 BCE) overlaps with the end of the Iron Age Cold Period. Conversely, wetter conditions with higher lake levels, lower salinity and meromixis coincide with the Roman Warm Period, the Medieval Warm Period and the middle–late LIA (Fig. 2).

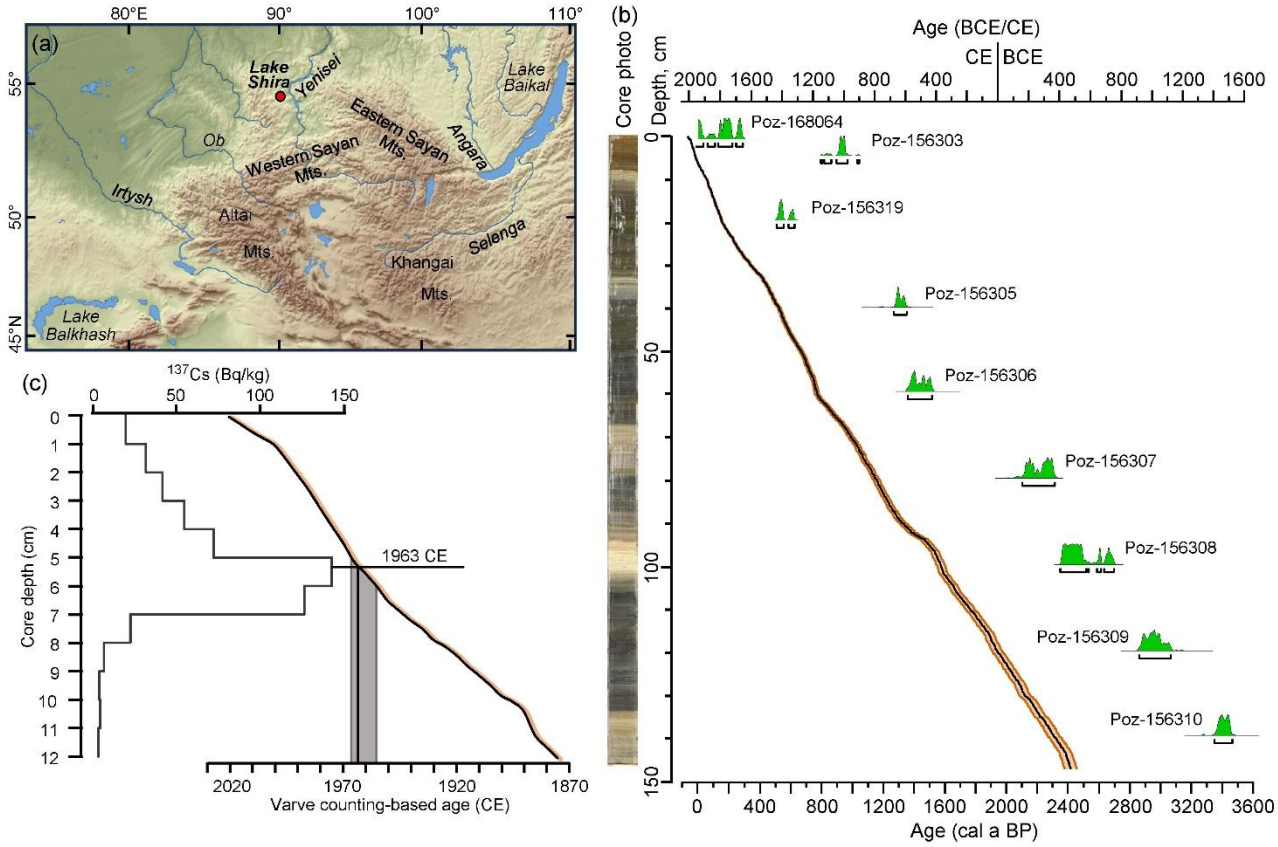


Figure 1. (a) Location of Lake Shira; (b) photograph of Sh-II-1 surface with varve-based age-depth model (black line, orange error range) and calibrated ages of nine AMS ^{14}C dates (green silhouettes, 95% CI) plotted for comparison; (c) ^{137}Cs concentrations in the upper 12 cm of Sh-II-1 aligned with the varve chronology, showing the peak in ^{137}Cs concentrations (142 Bq/kg) overlapping with the varve chronology (1955–1965 CE).

A comprehensive comparison with published regional and North Atlantic climate records indicates that this wet–dry pattern is primarily driven by North Atlantic sea-surface temperatures. Higher sea-surface temperatures, reflected in elevated Atlantic Multidecadal Oscillation (AMO) indices, promote more positive North Atlantic Oscillation (NAO) states and intensify mid-latitude westerly moisture transport into northern Inner Asia.

These findings add to the long-standing debate on the relationship between moisture and temperature in northern Inner Asia and show that, over much of the past 2500 years, warmer conditions have generally been associated with a wetter climate, whilst colder conditions have been associated with a drier climate. However, this relationship breaks down during the most recent climate warming, which began at the start of the 20th century, suggesting that regional annual air temperatures do not have a strong influence on precipitation, whilst thermal conditions in the North Atlantic region appear to play a pivotal role.

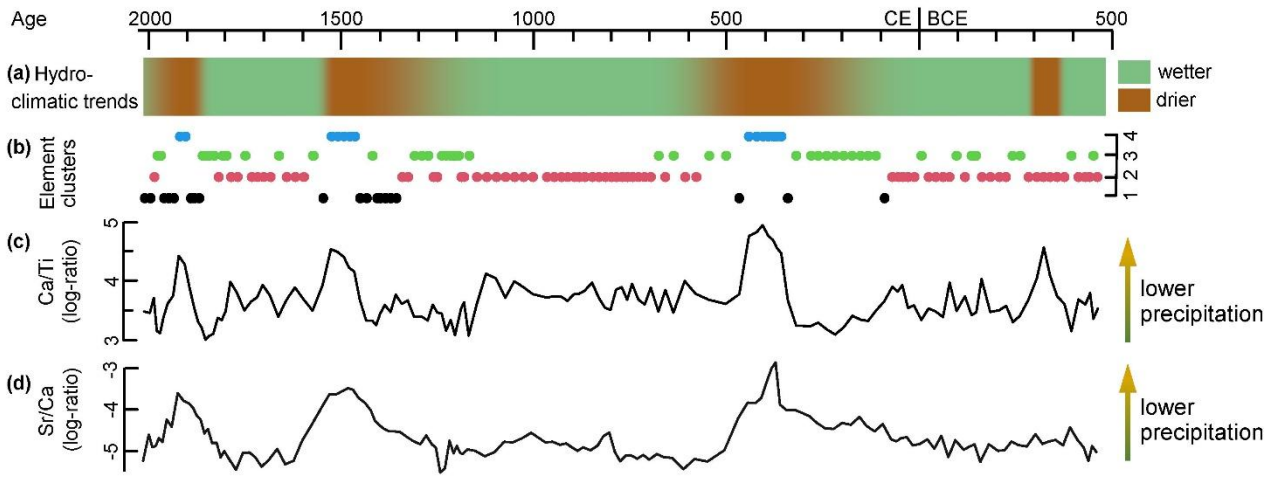


Figure 2. (a) Periods of relatively wetter and drier conditions inferred from the Lake Shira Sh-II-1 geochemical and mineralogical records; (b) elemental clusters based on XRF-derived sediment composition and (c) Ca/Ti and (d) Sr/Ca log-ratios from Sh-II-1.

Acknowledgments

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The Rise of Paralligatorids: Evolutionary Radiation Across Cretaceous Asia

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Keywords: Paralligatorids, Eusuchia, Cretaceous

Paralligatorids represent one of the most diverse clades of non-crocodylian eusuchians in the Cretaceous of Asia, yet their evolutionary history remains poorly understood due to fragmentary fossil material and unresolved phylogenetic relationships. Recent discoveries from Asia, combined with advances in computed tomography and comparative anatomy, provide an opportunity to reassess the origin, diversification, and biogeographic history of this important crocodyliform lineage.The synthesis is expected to provide new insights into the evolutionary radiation of paralligatorids and will explore whether Asia served as a major center of diversification for the clade. By integrating fossil discoveries with modern imaging techniques and comprehensive phylogenetic analyses, this study aims to refine the systematic framework of Paralligatoridae and to improve our understanding of the early evolution and biogeographic history of Eusuchia. By integrating new fossil discoveries with modern imaging techniques and comprehensive phylogenetic analyses, this synthesis can provide a revised perspective on the rise of Paralligatoridae and their role in the early evolution of Eusuchia.These findings not only refine the systematic framework of the clade but also highlight the importance of the Asian fossil record for understanding crocodyliform diversification prior to the emergence of modern crocodilians.

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IV. Isotope Geochemistry, Geochronology, Crustal Evolution

Developing petrologically informed geodynamic models

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Keywords: petrology, petrochronology, diffusion

The field of metamorphic petrology has undergone several evolutions beginning with the recognition that certain groupings of minerals reflect thermobaric conditions (index minerals and the facies concept of Eskola). This was followed by the realisation that these same minerals partition elements in a systematic way allowing temperatures and pressures to be quantified (classical thermobarometry) and that whole systems can be mapped in thermodynamic space to generate phase diagrams that capture the evolution of a rock (the pseudosection approach of Holland and Powell in the late 80's early 90's). These evolutions have progressed in lock step with the advancement of analytical capabilities that facilitate the collection of chemical (electron microprobes) and isotopic (SIMS and laser ablation mass spectrometry) information from mineral grains that enable the pressure-temperature-time (*P–T–t*) histories of rocks to be constrained (the field of "Petrochronology" pioneered by researchers such as Daniela Rubatto and Brad Hacker in the early 2000's). Despite these advances we are still faced by the challenge that the rocks we collect and analyse provide only a snapshot of the journey a single sample takes through an orogenic (mountain building) cycle.

A potential path to address this issue is the application of diffusion geospeedometry where the zoning profiles of different mineral can be used to construct a detailed temperature–time history for rocks – as always, a key mineral in this endeavour is garnet. Diffusion chronometry coupled with thermochronometers and 4+ cation thermometers allow more detail on *P–T-t* paths to be constrained. However, there now exists a dichotomy in the results produced by each approach wherein diffusion based geospeedometry studies generally yield timescales that are orders of magnitude faster that the classical U–Pb geochronological investigations. Begging the question how much of an orogenic evolution are we capturing and are orogenic events long and slow or constructed through a series of pulses? In this talk I will present progress towards the integration of phase diagram tools, diffusion processes, geochronological and petrological datasets with geodynamic models to constrain the evolution of lower crustal rocks during orogenic cycles.This approach, in our opinion, is the obvious next evolution in metamorphic petrology and is being enabled by the concomitant advances in both open-source geodynamic codes, in this case Underworld, and increasing computational power (both at the desktop and supercomputer level).These developments enable individual researchers to develop and test multiple scenarios to see what is plausible based on real geological data and the physics of rock systems at their desk rather than waiting for access to scarce resources such as access to national supercomputer facilities.

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Zircon melt-mediated coupled dissolution-precipitation and the effect on calculated ages: an overlooked mechanism of zircon modification, implications for CAOB

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Zircon incorporates trace and rare earth elements (REEs), this compositional flexibility, combined with exceptional durability, makes zircon an important U–Th–Pb geochronometer and recorder of the physicochemical conditions of crystallization. Solid-state diffusion of most elements in crystalline zircon becomes significant only under extreme conditions (> 900 °C; Hoskin and Black 2000) and thus chemical and textural modifications observed at lower temperatures must result from alternative mechanisms of element transport. Radiation damage is considered a key process facilitating such modifications by transforming crystalline zircon into a metamict, amorphous structure, where structural disorder enhances elemental diffusion, promotes fluid-mediated leaching, and permits partial recrystallization (Corfu et al. 2003). More recently, coupled dissolution–precipitation (CDP) has emerged as an alternative mechanism capable of producing both chemical and textural modification in zircon without the need for high-temperature solid-state diffusion (Geisler et al. 2007). During CDP, dissolution of the parent mineral is immediately coupled with precipitation of a more stable product, while an interconnected pore network maintains communication between the reaction interface and the external fluid (Putnis 2009). Experimental evidence that fluids can modify zircon, inducing Pb loss, was first provided by Pidgeon et al. (1966), since then, numerous chemical and microstructural changes have been attributed to fluid interaction and interpreted as metasomatism, recrystallization, dissolution–reprecipitation, annealing, alteration, or replacement (Schaltegger et al. 1999; Hoskin and Schaltegger 2003; Rubatto et al. 2017). Experimental fluid-mediated (FM)-CDP produces homogeneous cathodoluminescence (CL) or back-scattered electron (BSE) domains that truncate primary oscillatory zoning and commonly form embayments and channels associated with porosity, although the accompanying chemical changes vary considerably (Geisler et al. 2007; Harlov et al. 2023). Comparable transgressive textures widely reported from natural zircon in both metamorphic and igneous rocks affected by late-stage hydrothermal alteration are generally interpreted as products of FM-CDP (Rubatto 2017; Wang et al. 2024). CDP may also occur in the presence of melt. Geisler et al. (2007) proposed a melt-mediated mechanism (MM-CDP) based on zircon synthesis experiments and observations from Chernobyl lavas. In both cases, curved reaction fronts associated with pores and channels recorded rapid chemical exchange between melt and zircon, producing Y- and U-depleted domains within days. Natural examples of MM-CDP have subsequently been documented in both magmatic and metamorphic rocks, although they remain relatively uncommon (Halpin et al. 2020; Spier et al. 2022, 2024; Daczko et al. 2024). These studies demonstrate that MM-CDP can redistribute trace elements and isotopes, modify zircon chemistry, and disturb U–Pb systematics. The only dedicated experimental study of MM-CDP (Asimus

et al. 2024) reacted MudTank zircon with intermediate and mafic melts at 0.9 GPa and 1100–1180 °C for up to 3.5 days. The resulting textures and disturbed U–Pb systematics demonstrated that zircon replacement by melt can occur rapidly and generate apparent age variations exceeding 100 Myr. Melt involvement has also been widely discussed in relation to zircon rim formation during high-grade metamorphism (Kelsey et al. 2008; Rubatto 2017). However, these studies generally invoke dissolution followed by subsequent zircon crystallization, rather than in situ replacement by MM-CDP. Despite increasing evidence from both experiments and natural examples, MM-CDP remains under-recognized as a mechanism capable of modifying zircon texture, chemistry, and geochronology. On an example of zircon from a migmatitic metagranite (Štípská et al. 2026), we show extensive modification by MM-CDP. High-resolution CL, BSE, and SE imaging revealed replacement textures not visible in CL alone. Rounded crystal terminations, embayments truncating oscillatory zoning, convex pits and bulges, microscale porosity, and mineral-bearing pores document repeated episodes of CDP. Replacement preferentially initiated at crystal margins but locally affected zircon interiors through fractures or focused reaction channels. The wide range of observed textures reflects variable degrees of chemical equilibration between zircon and melt. Because fluid- and melt-mediated CDP generate similar zircon textures, melt involvement was evaluated using independent geological constraints. Migmatitic field relationships, mineral assemblages, and P–T estimates above the wet solidus indicate melt presence during zircon modification. In particular, secondary Grt–Ms–Bt–Ttn–glass inclusions associated directly with replacement domains constrain MM-CDP to approximately 16–11 kbar and 730–700 °C. Integration of high-resolution imaging with LASS-ICP-MS analyses identified inherited zircon (c. 540–590 Ma), protolith crystallization (c. 507–496 Ma), and Carboniferous zircon re-equilibration (c. 338–348 Ma). Intermediate dates mainly reflect incomplete replacement and mixed analytical volumes rather than discrete geological events. MM-CDP substantially modified zircon chemistry by depleting REE,Y,Th, and P while enriching U, Hf, and Nb, producing compositionally purer zircon towards equilibrium with melt and neighbouring minerals, whereas elevated LREE concentrations are attributed primarily to minute mineral and glass inclusions.These results demonstrate that MM-CDP is an efficient mechanism of zircon re-equilibration during high-grade metamorphism and should be considered alongside zircon dissolution and new zircon growth in models of metamorphic zircon evolution.

We suggest the melt-mediated CDP should be added to major mechanisms of metamorphic zircon formation. We speculate that MM-CDP dominates in the presence of low-temperature melts above the wet solidus (~700–800 °C), while with increasing temperature zircon dissolution into melt and its crystallization from melt (e.g. Kelsey and Powell, 2011), at different times and places from the dissolution, plays an increasing role.The effects of zircon MM-CDP involve smears of concordant dates caused mainly by variable Pb-loss.This is possibly due to sampling a mixture of replaced and original zircon at the scale of the analytical spot, resulting in misleading calculated ages. Dating of zircon affected by MM-CDP thus produces concordant age smears, making discordance filters alone unreliable.These age smears have been often interpreted as prolonged duration or repeated events, however, most of dates within these age smears may be rather geologically meaningless. Combination of a discordance filter with textural type of zircon, avoiding places affected by typical MM-CDP textures such as porosity or replacement channels, visible in high-resolution BSE but hardly recognizable in CL alone, may give more credit to the calculated ages. Examples from CAOB will be discussed.

Upper Mantle Structure and the Amurian Plate Boundary from Surface Wave Tomography

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Keywords: Surface wave tomography, Mongolia, Amurian Plate

A 3D radially anisotropic S-wave model of eastern Eurasia and Mongolia was constructed using multimode dispersion curves of Love and Rayleigh waves from 1655 teleseismic events (Mw>5.8; 2009–2021). Our model reveals strong lateral velocity variations at 70–100 km depth: slow anomalies mark western Mongolia, while fast anomalies characterize stable eastern Mongolia. Positive anisotropy (SH>SV) dominates the upper 100 km, except northeast of the Altay Mountains. Slower SV speeds beneath the Hangay Dome indicate partial melting driving regional uplift. Fast velocities in eastern Mongolia delineate the lithospheric boundary of the western Amurian Plate.

Introduction: Mongolia, forming part of the Central Asian Orogenic Belt (CAOB), sits at the boundary between the Siberian Craton to the north and active intraplate deformation regimes driven by the Cenozoic India-Eurasia collision and Pacific Plate subduction. It straddles the transition between the Eurasian and Amurian plates. Zonenshain & Savostin, (1981) first proposed the Amurian microplate's independent southeastward motion relative to Eurasia; however, its boundary geometry and mantle lithospheric drivers remain controversial.This study utilizes multimode surface wave tomography across dense regional networks to constrain upper mantle velocity structures and dynamic processes underlying Mongolia, the Amurian Plate and Central Eurasia.

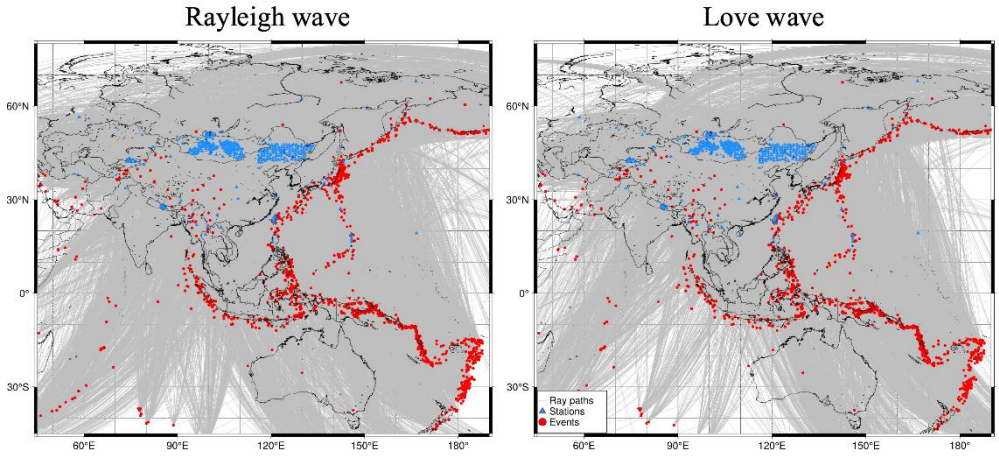


Figure 3. Ray-path coverage for the fundamental-mode Rayleigh and Love waves at 100 s. Blue triangles indicate seismic stations, and red circles indicate events.

Data and Methodology: We analyzed three-component broadband seismograms from 425 stations (Mongolian, GSN, PASSCAL, and NECESSArray) recording 1655 teleseismic events (Mw ≥ 5.8, distance > 1000 km) (Figure 3). We applied Yoshizawa & Kennett, (2002, 2004) 3-stage inversion framework: (1)

extracting path-averaged multimode Rayleigh and Love dispersion curves via the Neighborhood Algorithm; (2) constructing 2D phase velocity maps incorporating finite-frequency ray-path effects; and (3) inverting local dispersion curves into 1D anisotropic S-wave profiles (Tarantola & Valette, 1982) to assemble a 3D S-wave velocity model.

Results and Discussion: At the regional scale, slow isotropic S-wave speeds ($\beta_{iso} = \sqrt{\frac{2}{3}\beta_V^2 + \frac{1}{3}\beta_H^2}$) mark active tectonic zones (western Mongolia,Tibet, marginal seas), whereas fast velocity roots persist beneath stable cratons (Siberia,Tarim, Ordos, Sichuan) to 150 km depth. Cross-sections reveal strong velocity contrasts along the Stanovoy Range at 80–150 km depths.The western Amurian Plate exhibits a relatively thin (~70 km) but stable lithosphere, thinner than surrounding cratons, driving plate motions across eastern and western Mongolia. Positive radial anisotropy ($\xi = \left(\frac{\beta_H}{\beta_V}\right)^2$) dominates the regional lithosphere.

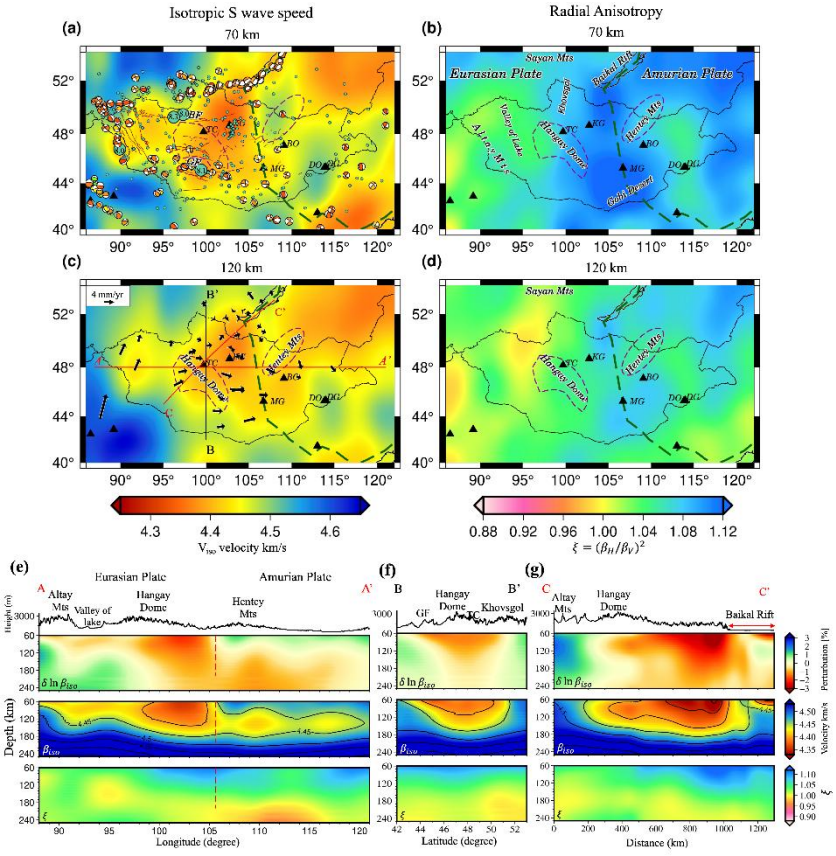


Figure 4. (a–d) Horizontal slices of S-wave velocity ($\boldsymbol{\beta_{iso}}$) and radial anisotropy ($\boldsymbol{\xi}$) at 70 and 120 km depths beneath Mongolia. (e–g) Cross-sections of $\boldsymbol{\beta_{iso}}$ perturbation, absolute ($\boldsymbol{\beta_{iso}}$), and ($\boldsymbol{\xi}$) along profiles A–A′, B–B′, and C–C′. Black triangles indicate Holocene volcanoes; green/red dashed lines represent the Amurian plate boundary (Bird, 2003). Seismicity (IAG), focal mechanisms (GCMT), and GPS velocities (Calais et al., 2003) are overlaid.

In Mongolia, shallow (~ 100 km) S-wave speeds transition laterally from slow in active western Mongolia (Eurasian Plate) to fast in stable eastern Mongolia (Amurian Plate). Radial anisotropy indicates SH>SV above 100 km depth across most of Mongolia, switching to SH<SV below 150 km beneath the Hentey Mountains. Low-velocity anomalies extend to 150 km depth beneath northeastern

Hangay Dome and <80 km beneath the Khovsgol/Baikal rift. The combination of low SV and positive anisotropy at 70–150 km suggests partial melting and lithospheric delamination beneath Hangay (Feng, 2021; Ganbat et al., 2024; Zhao et al., 2021). Conversely, eastern Mongolia transitions to faster velocities, marking the sharp western boundary of the Amurian plate (Figure 4).

Conclusions: A new 3D anisotropic S-wave model reveals a clear lithospheric velocity contrast across Mongolia between the Eurasian and Amurian plates (<100 km):

- Western Mongolia: Slow anomalies extend to 100 km beneath Altai Mts (India-Eurasia collision) and to 150 km beneath Hangay Dome, indicating partial melting and lithospheric delamination.
- Eastern Mongolia: Fast anomalies mark a thin (~70–100 km) but stable Amurian mantle lithosphere.

These upper mantle structural differences directly govern differential plate motions across eastern and western Mongolia.

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Tracing the evolution of the supercontinent cycle through Hf isotopes in the Mongolian Accretionary Collage

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The Wilson cycle has long been considered a compelling theory for explaining plate tectonics. However, the relationship between long-lived accretionary orogens and supercontinent assemblies remains unclear. In this paper, we revisit the supercontinent cycle, focusing on the hafnium isotope trends of the Precambrian Mongolian Ribbon (PMR) and the Mongolian Accretionary Collage (MAC). These features may indicate the evolution of two successive external oceans in the Central Asian Orogenic Belt (CAOB). Based on this proposal, we suggest that extroversion, rather than orthoversion or introversion, is the primary driver of supercontinent formation. A compilation of 5706 Hf isotopes from zircon found in magmatic and detrital rocks related to subduction in the PMR and MAC reveals two distinct subduction patterns: one of external advance and one of external retreat. These patterns switch at the assembly of each presumed supercontinent (2000, 1000, 540 and 260 Ma). The Hf isotopes related to subduction reflect the evolution of the PMR from around 2500 to 550 Ma and of the MAC from around 550 to 300 Ma. Furthermore, two phases of the retreating mode are observed from around 2000 Ma to 1000 Ma, and from around 400 Ma to 300 Ma, while three phases of the advancing mode occurred from around 2500 Ma to 2000 Ma, from around 750 Ma to 550 Ma, and from around 550 Ma to 400 Ma. Therefore, we propose a cycle of extroversion modulated by alternating periods of advancing and retreating modes of subduction between the assemblies of Columbia, Rodinia, and Gondwana, which terminated with the assembly of Pangaea. Our hafnium model suggests that an interconnected cycle may govern the Earth's evolution and speculates that a feedback loop exists between advancing and retreating modes and between "top-down" and "bottom-up" processes, leading to a fully operative supercontinent cycle. Finally, the Mongolian Accretionary Collage and the Precambrian Undifferentiated Ribbon Hf signatures seem to be controlled by the global Hf records. In addition, similar studies in South America show that the Hf isotope database also follows global Hf patterns. In conclusion, both areas show that Hf trends recorded in accretionary orogens are controlled by global plate processes and thus the supercontinent cycle.

Petrogenesis and metamorphic records of the eastern Alashan block (NW China): insights into the making of a Cordillera-type paleo-margin

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Keywords: Central Asian Orogenic Belt, Alashan block, High-grade metamorphism

The Alashan block preserves key tectonic records of the construction of the southern Central Asian Orogenic Belt and the transition from Rodinia to Pangea. Our study presents new geochemical, isotopic and geochronological data that constrain, for the first time, the petrogenesis of early Paleozoic metamorphic amphibolites, micaschists and migmatite in the eastern Alashan block.The results suggest that the protoliths of amphibolites were derived from a moderately enriched mantle source during late Mesoproterozoic–early Neoproterozoic time, in an intra-plate setting.The host metasediments were deposited during continental rifting of the same age and show a detrital affinity with the Ordos block. Combined petro-structural, metamorphic and geochronological studies reveal that the northernmost rocks record a Silurian prograde (M1) metamorphic event, overprinted by a regional Devonian Barrovian-type (M2) metamorphic event.Together with the cessation of continental arc magmatism (ca. 458–436 Ma), this suggests that the D1-M1 event (ca. 430 Ma) reflected northward underthrusting of the eastern Alashan block.The subsequent Barrovian metamorphism (ca. 411–394 Ma) and concomitant magmatic resurgence (ca. 423–397 Ma) reflected increasing heat flow associated with supra-subduction thickening (D2-M2) and crustal melting.This sequence depicts the development of an early Paleozoic Cordillera-type paleo-margin in the eastern Alashan block, affected by a late phase of Andean-type shortening and thickening, and contrasts with the evolution of the neighboring North-China craton to the east. Instead, the timing and duration of early Paleozoic metamorphic and magmatic events recorded in the Alashan block are comparable to those recorded in the Dunhuang block to the west.This tectonic scenario is tested against recent full-plate tectonic reconstruction models for the Paleozoic and represents a new contribution to the regional geodynamic model for the assembly of the Tarim–North China collage in the southern Central Asian Orogenic Belt.

Acknowledgments
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V. Mineral Resources and Metallogeny

Evolution of Ore-Forming Fluids in the Tsagaan Suvarga Porphyry Cu-Mo Deposit, South Mongolia: Inferred from Stable Isotopes and Fluid inclusions

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Keywords:Tsagaan Suvarga, Porphyry Cu-Mo, Adakitic magma, Stable isotopes, Fluid evolution.

The Tsagaan Suvarga porphyry Cu-Mo deposit is situated within the Late Paleozoic accreted terranes of the South Gobi, which tectonically comprise mid- to late Paleozoic basaltic to dacitic volcanic and sedimentary rocks intruded by Late Devonian and Carboniferous granitoids. Metallogenically, the deposit is a critical component of the Tsagaansuvarga ore district, located within the Oyutolgoi-Tsagaansuvarga metallogenic belt of the South Mongolian Metallogenic Megaprovince.

The mineralization (2000 x 450 x 250 m) is structurally controlled by NE-trending faults and hosted within the Late Devonian Tsagaan Suvarga intrusive massif dated at 370.9-324.6 Ma (e.g., Lamb and Cox, 1998; Berzina et al., 1999; Watanabe et al., 2000; Tungalag et al., 2009).

The ore-bearing plutons exhibit typical subduction-related I-type, metaluminous granitic features characterized by prominent negative Nb-Ta anomalies, adakitic affinity (HREE depletion), and primitive initial $^{87}Sr/^{86}Sr$ ratios (0.7027-0.7038), indicating a mantle-derived magma source. Hypogene mineralization manifests as quartz-chalcopyrite-molybdenite stockworks and veins surrounded by well-defined potassic, quartz-sericite, and propylitic alteration halos. To unravel the source, environment, and temporal evolution of the mineralizing system, this study integrates fluid inclusion micro thermometry with stable isotope ($\delta^{18}O$, δD, $\delta^{13}C$) geochemistry.

Fluid inclusion assemblages within ore-associated quartz veins comprise coexisting liquid-vapor, liquid-CO_2-vapor, and vapor-only inclusions. Primary liquid-vapor inclusions homogenize at temperatures (T_h) ranging from +277°C to +340°C (mean: +333°C) with moderate-to-low salinities of 5.8-6.9 wt.% NaCl eq., capturing the core stage of porphyry ore precipitation. In contrast, secondary fluid inclusions trapped along micro-fractures record a distinct low-temperature cooling stage, yielding T_h values of +120°C to +190°C (mean: +148°C).

Stable isotope data reveal remarkably tightly constrained $\delta 18O_{quartz}$ values between +9.15‰ and +11.8‰ (predominantly +10.1‰ to +10.9‰). Utilizing the empirical quartz-water fractionation framework at the mineralizing temperature of +330°C, the calculated oxygen composition of the hydrothermal fluid ($\delta^{18}O_{fluid}$) spans +3.25‰ to+5.9‰. Syn-ore sericite yields a uniform δD value of 110‰. These isotopic vectors plot precisely within the primary magmatic water box and perfectly align with regional adakitic granitic fluids, confirming that the early high-temperature metalliferous fluid was entirely magmatic-hydrothermal in origin. Furthermore, while the core ore-fluid maintains a strictly magmatic signature, comparison with peripheral alteration zones exhibiting enriched hydrogen values (up to -19.3‰) highlights a substantial hydrodynamic influx of paleo-meteoric water during the evolution of the hydrothermal fluid. The paragenetically late stage is represented by vein-calcite, which exhibits a magmatic carbon footprint ($\delta^{13}C_{PDB}$ =-7‰) but a significantly enriched oxygen signature ($\delta^{18}O_{SMOW}$ = +18.2‰). This heavy oxygen enrichment reflects intense isotopic fractionation governed by the sharp

temperature drops (+148°C) and subsequent structural collapsing of the magmatic core, facilitating late-stage meteoric water.

TheTsagaan Suvarga porphyry system originated from mantle-derived adakitic magmas, and the main stage of copper-molybdenum mineralization within the quartz veins was driven by moderate-temperature magmatic fluids.The thermodynamic evolution, driven by boiling, progressive conductive cooling, and ultimate mixing with meteoric waters, collectively caused metal to precipitate, leading to the economic Cu-Mo deposit.

Tectono-magmatic Framework and Gold Metallogenic Potential of the EastTianshan–Beishan Metallogenic Belt, Central Asian Orogenic Belt

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Keywords: East Tianshan–Beishan; Central Asian Orogenic Belt; gold metallogenesis; tectono-magmatic evolution; metallogenic system

The East Tianshan–Beishan metallogenic belt, located in the southern Central Asian Orogenic Belt (CAOB), is one of the most important gold and polymetallic resource regions in western China (Xiao et al., 2004). Although numerous gold deposits and occurrences have been identified in this belt, the regional metallogenic framework (Figure 1), controlling factors, and exploration potential remain insufficiently understood. In this study, we compile a comprehensive dataset of 363 gold deposits and occurrences to investigate the temporal–spatial distribution, geological controls, and metallogenic potential of gold mineralization in the EastTianshan–Beishan belt. Gold deposits in this region mainly include magmatic-hydrothermal, volcanic-hosted, and structurally controlled types. Statistical analysis shows that gold mineralization is strongly concentrated during the Late Carboniferous to Early Permian, corresponding to a critical stage of regional tectono-magmatic evolution. Extensive intermediate–felsic magmatism, volcanic activity, and large-scale deformation during this period provided favorable conditions for heat transfer, hydrothermal circulation, and gold enrichment.The spatial distribution of gold deposits demonstrates strong coupling between magmatic activity and regional structures. Intermediate–felsic intrusions and their contact zones are closely associated with magmatic-hydrothermal and skarn-type gold deposits, whereas Late Paleozoic volcanic rocks and volcanic centers favored volcanic-related mineralization. Regional-scale ductile shear zones acted as important pathways for hydrothermal fluid migration and ore deposition (Cai et al., 2012).These features indicate that various gold deposit styles represent different expressions of a regional metallogenic system controlled by tectonic evolution, magmatism, and structural architecture (Jiang et al., 2014). Based on integrated geological, geochemical, and geophysical information, regional mineral potential was evaluated using the MRAS method. A total of 21 prospective areas were delineated, including eight targets with predicted gold resources exceeding 50 t. Several key areas, including Gexingshan, Shiyingtan, Kangguer, Xiaoxigong, and Jinwozi, exhibit significant exploration potential. Recent discoveries such as the Qianhongquan–Heishan Beitan large gold deposit in southern Beishan further demonstrate the potential for large-scale gold discoveries in this region.

This study establishes a regional metallogenic framework for gold deposits in the East Tianshan–Beishan belt and highlights the combined roles of tectono-magmatic evolution and structural controls in gold concentration.The results provide important implications for understanding Late Paleozoic gold metallogenesis in the CAOB and guiding future exploration in western China.

Acknowledgments

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Mineral Forecasting Based on Artificial Intelligence and Empirical-Statistical Methods

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Improving the efficiency of forecasting mineral deposits requires the introduction of methods that provide accelerated solution of geological problems. Processing the available amount of geological data requires not only improving the structure and performance of GIS databases, but also identifying hidden relationships in the distribution of available geological information. Computer technologies make it possible to identify such patterns, visualize the obtained data, and thus form fundamentally new predictive bases, while also serving as a technical basis for automating such constructions.

In addition to the use of computer technologies, forecast automation requires a systematic approach to the use of geological knowledge. The forecast and search models adopted in the domestic geological exploration industry are formed on the basis of modern achievements in the study of mineral deposits and the regularities of their placement. However, despite their effectiveness at the stage of prospecting, they have limited applicability at the stage of regional forecasting, since the general set of elements of such models does not take into account the fundamental difference between the set of prerequisites for the formation of deposits (criteria) and the set of properties or characteristics of any geological phenomenon (signs). At the same time, the software and mathematical tools in these models have not undergone significant changes in recent years.

Modern technologies (big data, neural networks, machine learning, etc.) actively contribute to the development of spatial-statistical methods in predictive metallogenic research. These methods are based on two key approaches: empirical-statistical (data driven) and geological-genetic (knowledge driven).

The methodology of predictive metallogenic analysis, based on an empirical and statistical approach, uses GIS software and digital modelling of spatial data. Spatial relationships between known mineral deposits or occurrences and specific geological, geochemical, and geophysical parameters presented in digital spatial data sets are analysed. Statistical methods used in this approach include logistic regression, weights-of-evidence, and neural networks. Obviously, a forecast based on a set of empirical data will be demanding in terms of their volume, distribution, and detail, so it can only be implemented in well-studied territories.

Modelling methods based on the genetic approach differ from data-based analysis by using conceptual models of ore formation rather than empirical relationships. The analysis is implemented in the GIS environment using such analysis methods as index overlay and fuzzy logic. The advantage of this approach is the possibility of its application in poorly studied territories.

Simultaneous use of the two approaches described above in predictive constructions is a factor in improving the quality of the forecast.

The technological chain of the forecast methodology developed at the Karpinsky Institute includes a number of consecutive stages: compilation of geological-genetic and geological-forecast models; data collection and preparation; formation of forecast coatings; stages of forecast automation and verification; stage of analysis and rating of prospective areas.

The main advantage of the proposed technology is the integrated use of two complementary approaches: geological-genetic approach, which allows to formalize expert knowledge and identify areas favourable for ore formation based on fundamental criteria, and empirical-statistical approach,

based on the use of machine learning methods and basin analysis, which provides an objective, quantitative analysis of large arrays of spatial geological data.The approach allows to identify hidden patterns, associations of features, minimizing the subjective factor. Combining these methods makes it possible to move from qualitative estimates to quantitative, evidence-based forecasting.

The implementation of this methodology in the practice of geological mapping and monitoring makes it possible to systematize the forecasting process at the regional level, increase the objectivity and validity of identifying promising areas and setting up further forecasting and revision or prospecting operations, ensure reproducibility of results by different executors, and create a digital basis for constantly updating forecast maps as new data becomes available.

Thus, the developed methodology is an effective tool for managing the use of mineral resources, which helps to optimize financial and labour costs at the early stages of geological exploration of mineral resources and is aimed at strengthening the mineral resource base by identifying new promising objects. Further development of the methodology is seen in the integration of a wider range of data and the use of a wider set of analysis algorithms.

Reconnaissance of critical raw materials on the southwestern fringe of the Khangai Mountains - conclusions from a joint Polish-Mongolian research project.

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Keywords: Critical raw materials, field reconnaissance, geochemistry.

In 2023, the Polish Geological Institute - National Research Institute (PGI and the National Geological Survey of Mongolia (NGS) executed a formal Project Agreement for the initiative entitled "Reconnaissance of Critical Raw Materials in Mongolia – Recognition of Molybdenum and Tungsten Occurrences". This project, implemented over three years, aimed to identify and evaluate geological data pertinent to research on critical raw materials and metals, and to define their occurrences within designated locations.

PGI and NGS have undertaken reconnaissance activities across three designated areas, encompassing a total surface area of 256.4 km^2. The research zones include Beliin Bulag and Zadgai Bulag, both located in Bayankhongor Province, as well as Taishir, situated within Govi-Altai Province. The selected areas are situated in the southwestern region of the Khangai Mountains and at the periphery of this mountain range (Fig. 1). From a tectonic perspective, these regions belong to the cratonic, Proterozoic terranes of the Central Asian Orogenic Belt, which encompasses Tarvagatay, Baydrag, and Zavkhan, all of which are located north of the Main Mongolian Lineament (Badarch et al., 2002). The lithologies present in this region demonstrate a complex structural framework that has been shaped by multiphase geological evolution, characterized by tectonometamorphic transformations, plutonism, and vertical movements within the tectonically active interior of Central Asia (Levashova et al., 2010; Guy et al., 2021; Štípská et al., 2023).

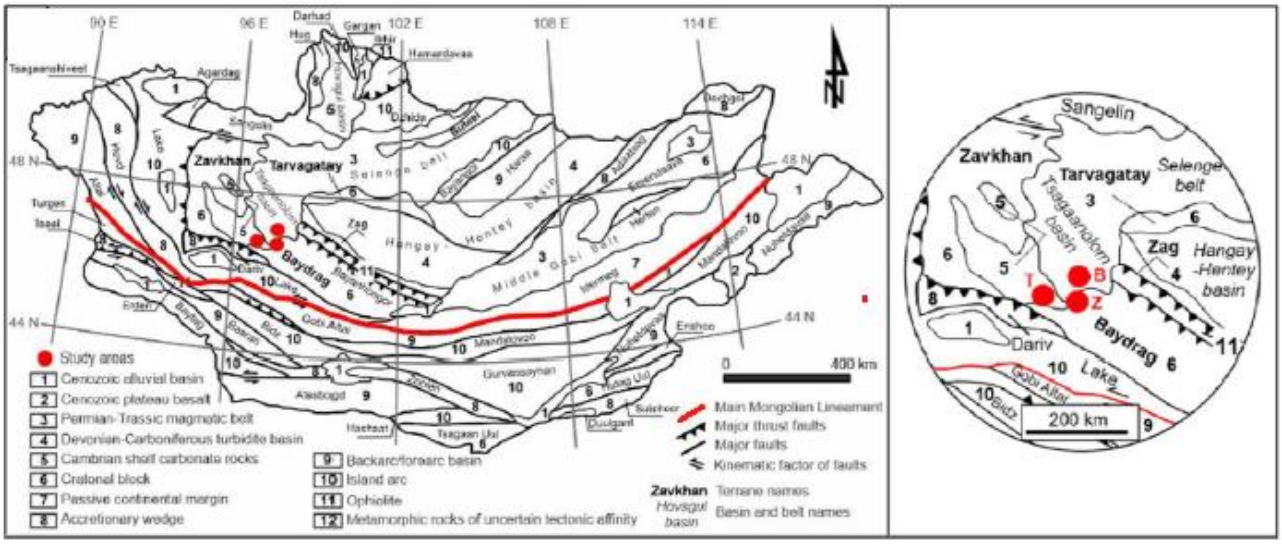


Fig. 1. Location of the project on tectonic map of Mongolia (after: Badarch et al., 2002, modified)

Methodology

The reconnaissance primarily focused on the Permian granitoids and their metamorphic cover. During fieldwork, the team conducted systematic geological observations, identified various rock types, and

performed chemical analyses using a portable X-ray fluorescence spectrometer (pXRF). Rock samples were collected for laboratory testing, UV light observations were made, and placer samples from intermittent streams were gathered. Photographs of geological exposures and rock specimens were documented.

Laboratory testing includes the study of geochemical, mineralogical, and petrographic properties. Thin sections were analyzed for mineral composition under transmitted and reflected light, while a scanning electron microscope with energy dispersive spectroscopy (EDS-SEM Leo Zeiss) was used for detailed analysis. Chemical analyses were performed using wave dispersive X-ray fluorescence spectrometry (AXIOS WDXRF), with gold concentrations checked by graphite furnace atomic absorption (GF AAS). Mineralogical analyses utilized a PANalytical X'pert Pro diffractometer, and grains from placer samples were identified using a Hitachi SU-3500 scanning electron microscope with a Thermo Fisher UltraDry Compact EDS detector.

Results

During two seasons of fieldwork, research teams covered 143 km in Beliin Bulag, 182 km in Zadgai Bulag, and 126 km in Taishir, conducting over 2,500 pXRF analyses. A total of 879 rock samples were collected for lithogeochemical studies, alongside 346 samples for petrographic analyses and 89 placer samples.

The assessment of Beliin Bulag showed low mineral potential, with no significant mineralization zones found. Major element analysis indicated low sulfur content, suggesting limited sulfide mineralization. While some elevated ore mineral concentrations were detected in specific areas - primarily in the contact zones between mafic rocks and granites, as well as in igneous rocks and crystalline limestones, and within veins and pegmatites - the results do not indicate any economic viability.

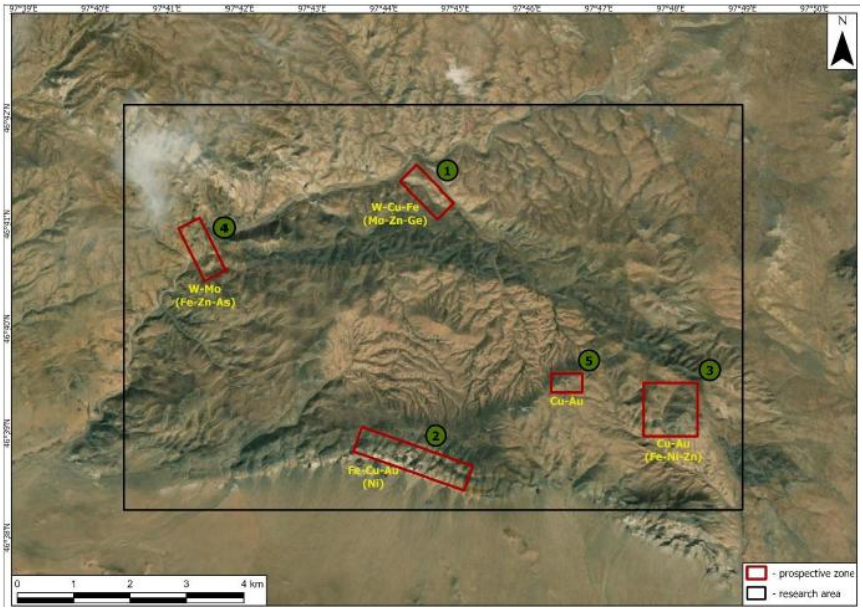


Fig. 2. Areas with increased mineralization occurrence, Zadgai Bulag.

The Zadgai Bulag area exhibited the most promising results among the studied zones, leading to the identification of five prospective areas (Fig. 2). Area 1 includes zones enriched in tungsten (>2.5 wt.%; thickness 1.5-2 m) and copper (>1 wt.%, 1-1.5 m). Additionally, the presence of malachite and azurite alongside magnetite has been observed. Area 2 is characterized by a significant enrichment in iron (>60 wt.%), along with recorded concentrations of copper (>1 wt.%), nickel (up to 0.41%), and gold (up to 0.78 mg/kg). Area 3 demonstrated enrichment in zinc (2.2 wt.%), nickel (up to 762 ppm), copper (>1 wt.%), and gold (1.95 mg/kg). Area 4 is associated with a quartz and epidote veins within granite, where tungsten enrichment was noted at 1789 ppm. Area 5 was identified based on minor occurrences of mineralized copper oxide rocks (> 0.89 wt.%). Notably, no extensive ore mineralization was detected in the region. However, the results of the prospecting may have been influenced by a lack of trenching and drilling.
The Taishir area has no signs of pneumatolytic or hydrothermal mineralization. The local igneous rocks have low biotite content, indicating minimal water presence during magma crystallization. Observations show low-temperature alterations and barren quartz and carbonate veins. Molybdenum and tungsten are found in trace amounts (under 100 ppm and 50 ppm, respectively), while copper concentrations are below 0.05 wt.% and rare earth elements reach up to 0.14 wt.%. Overall, surface studies indicate that the area shows limited raw material potential.

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Assessment of Geothermal Energy Resources in the Marcellus Shale

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Keywords: Geothermal resource assessment, Low-temperature geothermal resources, Monte Carlo simulation, Marcellus shale, Pennsylvania, Appalachian Basin

This paper presents a basin-scale model and assessment of geothermal energy resources in the Marcellus shale in the Appalachian Basin, integrating the most recent data. This research was conducted through the following tasks: (1) review heat transfer mechanisms, (2) collect and analyze the most recent geological, reservoir, and thermal data related to the Marcellus shale and the basin, (3) computations of thermal resource characteristics, (4) develop and validate a thermal model by integrating all available data, and (5) perform a systematic and comprehensive modeling to assess thermal energy stored in the Marcellus shale through Monte Carlo simulations.The results show that the total thermal energy stored in the Marcellus shale is 4.44×1014 Megajoules (MJ). Pennsylvania constitutes approximately 56% of the resources with a most likely value of 2.50×1014 MJ.Temperature ranges from 14 to 96 °C, which is classified as low-temperature resources suitable for geothermal heating system.The greatest stored thermal energy is located in northeastern Pennsylvania, especially in Sullivan, Columbia, Luzerne, and Wyoming counties.This method and its application to the Marcellus shale enhance the understanding of geothermal resources in the Appalachian Basin.

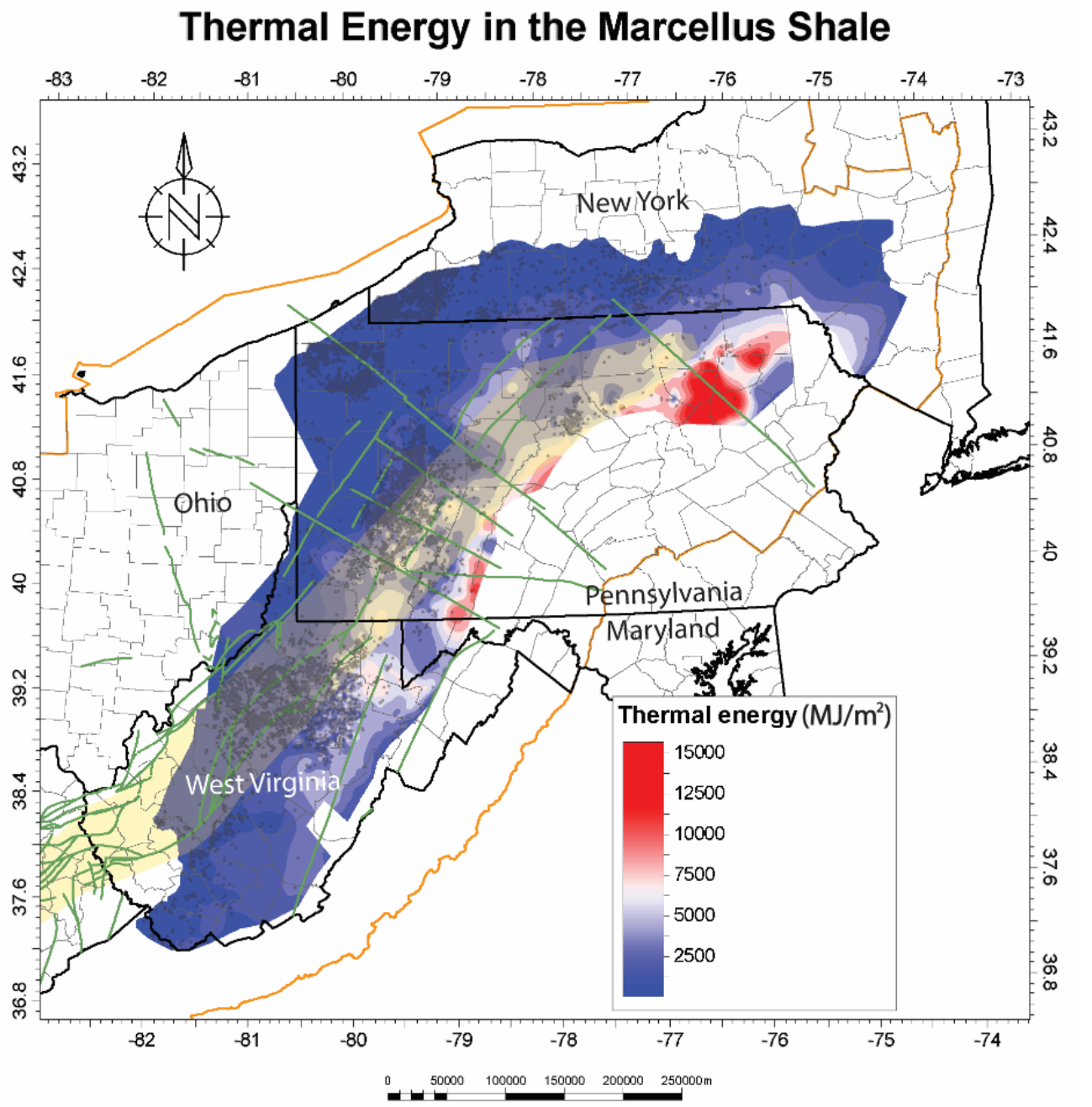


Figure 1. Best estimate (P50) of the thermal energy in the Marcellus shale from the probabilistic assessment. Orange line represents boundary of the Appalachian Basin.Yellow shaded area represents the RomeTrough. Green lines represent Precambrian fault lineaments. Black transparent points represent control points.

Compilation of the geological space digital models of the Greater Altai at a scale of 1:1M, aimed at forecasting ore deposits: the state of the art and proposals for intensifying scientific and practical cooperation between Russia, China, Mongolia and Kazakhstan

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Keywords: Greater Altai, cooperation, lithium and rare metal deposits

The Greater Altai region covers the border areas of four countries: Russia, Kazakhstan, Mongolia and China, providing a unique opportunity to solve topical issues of practical geology and metallogeny of transboundary territories. It is one of the largest mining provinces in the world. This region has long been known for its rich endogenous deposits of copper, lead, zinc, silver, gold, and iron, and more recently, rare metals. Cooperation on the study of the Greater Altai region began as part of an international project involving five countries, the "Atlas of Geological Maps of Central Asia and Adjacent Territories at a Scale of 1:2.5M", which has been implemented since 2002 through the joint efforts of Russia, Mongolia, Kazakhstan, China, and Korea.

State of the art. The geological study of the Russian part of the Greater Altai is quite high. It is completely covered not only by geological survey at a scale of 1:200,000, but also by large-scale survey at a scale of 1:50,000 over a significant territory. The territory well studied by gravimetric, aeromagnetic and geochemical surveys.

All these materials were taken into account when compiling the geological map of the Greater Altai in in the early 2010s. At the meeting in Ulaanbaatar, geological maps of adjacent territories of Greater Altai were exchanged with colleagues from China and Mongolia.

In 2020, Russia geologist launched a new project – monitoring of previously created 1:1M State Geological Maps including the territory of the Greater Altai. The first stage of these works was completed in 2024.

At this time, a new stage of geological mapping of the Greater Altai has begun in cooperation with the CAGS (Chinese Academy of Geological Sciences). Together with Chinese geologists, we decided to create a series of Greater Altai maps, including an updated geological map, a series of isotope data maps, tectonic map, and metallogeny map of igneous rocks. During this collaboration, the Greater Altai mapping boundaries were defined, digital materials were exchanged, and an agreement was reached on digital map presentation formats. Since the Chinese side (CAGS) was responsible for compiling the consolidated Greater Altai maps in national GIS formats, our digital materials were reworked for compatibility maps of the Russian and Chines parts of the Greater Altai.

To integrate cartographic materials into the International Greater Altai project and link them with adjacent territories, the geological map of Russian Altai and its legend were generalized and significantly simplified. Additional tectono-stratigraphic zoning was conducted, and a corresponding zoning scheme was compiled. The mineral resource map was further zoned metallogenically, and a minerogenic taxon diagram was compiled.

The first stage of the Greater Altai mineral resource map was compiled using data obtained during the compilation of a metallogenic map of Northern, Central, and Eastern Asia at a scale of 1:2.5M. This map contains approximately 300 mineral deposits within the Greater Altai region. Their distribution by country

is as follows: Kazakhstan (168 deposits), Russia (74 deposits), China (35 deposits), and Mongolia (18 deposits).

Suggestions for further cooperation. In order to further develop cooperation in exploring the Greater Altai, we believe the time has come to shift the focus of joint research toward mineral resources.The primary asset of the Greater Altai is, of course, the pyrite-polymetallic deposits of Rudny Altai. However, while these deposits are widespread in Kazakhstan and Russia, in China the Rudny Altai zone narrows and pinches out, and in Mongolia they are completely absent.Therefore, we believe that, given the recent interest from politicians and the public, lithium-rare metal deposits would be of interest for joint research between the four countries in the Greater Altai.

The Altai rare metal province extends as a wide belt (800× 200 km) from the Russia and Eastern Kazakhstan to China and Mongolia. In Kazakhstan and China, deposits are represented by rare-metal pegmatites, in Russia – by rare-metal porphyries. In Kazakhstan, rare metal deposits are genetically related to granites of the Kalba-Narym batholith and have an Early Permian age of 295-280 Ma. In Russia and China, the most important deposits are located in the Altai-Mongol and Central-Altai terranes and have an youngerTriassic-Jurassic age. In general, rare metal mineralization is controlled by granite intrusions ranging in age from the late Carboniferous to the Jurassic. Historically, the main objects of industrial exploitation have been the pegmatite deposits of Kazakhstan and China, but their resources are almost exhausted, so now more and more attention is being drawn to rare metal granite porphyries.

In *China* the largest rare-metal pegmatite deposits are located in the Chinese Altai, where more than 100,000 pegmatite veins are known. However, for most rare-metal pegmatites (such as Koktokay, Kaluan, etc.), synchronous granites have not been found.The origin of these rare-metal pegmatites is still controversial. Only recently have rare metal highly fractionated leucogranites been identified at the Koktokay deposit U–Pb ages of the leucogranites 224–220 Ma are in good agreement with U–Pb age of 219.8 ± 1-3 Ma of the No. 3 Pegmatite.The muscovite 40Ar/39Ar ages from the same leucogranite yield the age range of 182–177 Ma, indicating a new Early Jurassic hydrothermal event. In this regard, data on rare-metal granitoids (without pegmatites) of similar age in the Russian Altai are of particular interest.

In *Russia* greisen tungsten deposits and ore occurrences are widespread in the Alakha-Kalguty ore district. However, Li mineralization is established only at the Alakha (spodumene porphyry), Kalguty (ongonite) deposits and in the spodumene aplite dike in the Kungurdzharin intrusion.

Kalguty rare-metal–granite batholith hosts the Mo-W greisen and Mo-porphyry deposit of the same name.The duration of batholith formation exceeds 30 Ma (215-181 Ma).

In the eastern part of batholith (207 Ma), there is a belt of 125 porphyry dikes (204 ± 2 – 201 ± 1 Ma), 17 km long and 5 km wide. Rare metal ongonites compose 10 dikes (Li 0.1–0.27%, Cs 0.07-0.18%, P2O5 0.5-1.0%).The lithium mineral amblygonite (montebrasite, 8-9% Li2O) forms inclusions in Kfsp. Based on the results of isotope dating, five stages of magmatism are distinguished in the Kalguta ore-magmatic system (OMS). However, Li mineralization is evident only at stages III and IV of ongonite formation with an age of 202±5 and 195±1 Ma.

Alakha spodumene granite porphyries form two stocks, 1000 × 650 m and 400 × 250 m, intruding Early Devonian (413 Ma). tonalites.The Alakha stocks are composed of Mus-Spd-Kfsp-Ab- granite porphyry, the apical part by albitite. Spodumene granite porphyries contain Li_2O – 0.24–1.46, average – 0.98 %, Ta_2O_5 – 70–180 ppm, average – 114 ppm. U-Pb isotope ages for zircon of 183 and 188 Ma. Isotopic ages of 195±3 and 198.6±1.1 Ma are also given.The resulting dating are inaccurate because the zircon is high-uranium, metamictic, and gives a strong discordance in age values.The Alakha stocks are believed to be Early Jurassic and formed as a result of the crystallization of lithium silicic acid magma.

In *Kazakhstan*, the Novo-Akhmirovsky lithium-fluoride granite stock, located within the Irtysh shear zone in close proximity to the Kalba-Narym batholith, is of interest for joint research. The granite outcrops of the Novo-Akhmirovsky stock (S = 0.02 km2, dimensions 220 × 110 m) are oriented northeast. The central part of the stock is composed of medium-grained topaz-zinwaldite granite with facies transitions along the margins to porphyry varieties with a finer-grained matrix. Its predicted resources are estimated at 110,000 tons of lithium oxide.

In *Western Mongolia*, the Mo-W greisen deposits of Ulan-Ula (Kyzyl-Tau), Naringol, Sagsai, and others are also associated with Early Mesozoic magmatism (220-200 Ma). They were discovered by Soviet geologists in 1973 during exploration work in a 100-km border zone under the Intergovernmental Agreement between the USSR and Mongolia. Exploration and evaluation work was conducted in 1974-75. The Kyzyltau ore field may be proposed as a site for joint research. The igneous column here is represented by granitoids with a long formation history of approximately 100 million years and culminating 200 million years ago, which is consistent in age with Russian and Chinese rare metal deposits. Rare metal ores at the five sites are concentrated in quartz veins and stockworks, where they are represented by wolframite, scheelite, flurite, beryl, and molybdenite.

Significance for prospecting works. The almost synchronous formation of lithium and rare metal deposits in the Greater Altai makes it possible to correlate the petrological features of ore-productive magmatism at different depths of formation of rare-metal ore-magmatic systems. It appears that the formation of highly fractionated magmas, parent to pegmatites, occurred at considerable depth, while porphyry rare-metal magmas in the Greater Altai crystallized at shallow depths. If this is confirmed, then territories with rare metal porphyry intrusions can be considered promising for rare metal pegmatites at depth.

VI. Advanced Technology and Data Analysis

TheTopoAsia Initiative: A Multidisciplinary Framework for Integrating Deep Earth Dynamics and Surface Processes in Asia

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Asia is a geodynamically unique and complex region, characterized by intense tectonic activity, diverse landforms, and profound interactions between the deep Earth and surface environments.TheTopoAsia Initiative is a novel international research program designed to address the longstanding challenge of integrating deep Earth geodynamics with surface processes to understand the four-dimensional (3D space + time) evolution of the Asian continent and oceans.This paper presents the scientific rationale, overarching objectives, and methodological framework of the initiative. We argue that a holistic, continent-scale approach is essential to overcome the fragmentation inherent in current research, which often decouples mantle dynamics from surface responses.The initiative's core mission is to quantify the dynamic interactions between Asia's deep Earth and its surface systems, with a specific focus on tectonic dynamics, resource distribution, and environmental change.To achieve this,TopoAsia adopts an innovative "Four Co-" collaborative framework (Co-Planning, Co-Building, Co-Sharing, Co-Winning) to foster open science and equitable partnerships. In this talk, we outline the key scientific questions, the integrated methodological workflow (encompassing geophysical imaging, numerical modeling, and paleoenvironmental reconstruction), and the expected outcomes. By bridging the gap between the solid Earth and surface process communities,TopoAsia aims to deliver a step-change in our understanding of Asian geodynamics and provide a robust scientific foundation for evidence-based sustainable development across Asia and globally.

Digital Technologies for Regional Geological Studies: Integration of Geological Data, Mapping, and Artificial Intelligence

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Regional geological studies increasingly depend on the ability to integrate field observations, specialized geological databases, digital map production, national-scale geological models, and artificial intelligence within a unified information environment. The Karpinsky Institute has developed and operates a suite of digital technologies covering the full cycle of this work. They are used in the state geological mapping of Russia and were designed as interconnected components rather than isolated applications. Their practical purpose is to reduce repeated manual data transfer, standardize geological information, accelerate map production, support multiscale generalization, and provide geologists with direct access to accumulated knowledge in both field and office settings.

The scale of the operational environment is substantial. Each year, the Karpinsky Institute conducts geological monitoring over approximately 2 million km² at 1:1,000,000 scale, carries out new geological mapping over approximately 100,000 km² at 1:200,000 scale, and organizes 50–60 field geological teams. Approximately 20 TB of geological data are generated and processed annually. This production flow has shaped the architecture of the digital cycle: field data are recorded in structured form, transferred to primary and specialized databases, used in the compilation and standardization of geological maps, integrated into a unified geological mapping model, and published through national geological mapping resources.

At the field stage, SHERPA technology provides digital geological documentation on Android mobile devices. It supports various navigation basemaps, remote sensing data, geological maps, and georeferenced sketches. The system is used for the structured description of observation points, documentation of mine workings and geological outcrops, recording of heavy-mineral concentrate and lithochemical sampling results, route tracking, creation of target points, and synchronization of field-team databases. Each record is automatically linked to coordinates, date, author, photographs, samples, sketches, observation objects, and route segments. As a result, the geologist completes a route with a prepared digital package of materials rather than a collection of disconnected notes, photographs, tables, and GPS tracks. The SHERPA-Aero module extends this cycle to unmanned aerial vehicles, including planning of 2D and 3D missions, imaging of vertical faces, and rapid integration of aerial imagery into field projects. SHERPA has been used in Russian state geological mapping since 2020; a Spanish-language version was prepared in 2025, and the technology was transferred to the Geological Survey of Cuba for implementation that same year.

Artificial intelligence is being introduced directly into field workflows through the RockID–RockField system, which is currently under development. It is intended for offline identification of rocks and ores on mobile devices. The training dataset is being compiled from the collections of the Geological Museum of the Karpinsky Institute, collections assembled by field teams, and series of field photographs. The concept is not limited to returning a single class. When a phone is pointed at an

outcrop or specimen, the system is intended to display the most probable identification, closely related alternatives, and diagnostic features supporting the result, followed by step-by-step refinement. The system is therefore conceived as an explainable scientific field assistant rather than a black-box image-recognition tool.

The next level of the digital cycle is the Primary Field Geological Data Database. It integrates more than 2.1 million records of primary geological and geochemical data from state geological mapping. The database contains routes, outcrops, trenches and pits, boreholes, sampling points, complete geological descriptions, and the results of chemical and mineralogical analyses. Its interface allows users to select analytical results, construct petrochemical and geochemical diagrams, and export the required datasets in SHP, JSON, GeoJSON, and XLSX formats. The database is continuously updated with the results of each new field season and serves as a structured link between field documentation and subsequent interpretation.

Primary observations are supplemented by specialized national geological databases created at the Institute. These include databases of isotope-geochronological and isotope-geochemical determinations, stratotype descriptions of geological objects, mineral-resource objects, and prospective areas. The mineral resources database contains approximately 115,000 objects, including deposits, mineral occurrences, mineralization points, and geochemical and geophysical anomalies. A separate resource contains more than 6,000 areas with estimated prognostic resources in the Russian P1, P2, and P3 categories. For prospective objects, the databases store geological and mineragenic characteristics, the rationale for their identification, quantitative estimates of metallogenic potential and prognostic resources, reference analogues, recommendations for further exploration, maps, diagrams, and cross-sections. These databases provide structured source information for regional assessment and analysis of mineral-resource potential.

A separate group of technologies is intended for the standardization and production of geological maps. The Digital Library of Symbols for State Geological Maps contains approximately 13,000 standardized symbols. MapDesigner, a program developed at the Institute, automatically reads the B-code assigned to an object in the digital map model, identifies the corresponding reference symbol, and applies the required cartographic styling. The approach can be implemented in ArcGIS, QGIS, and web applications. In production, this reduces the styling of a single map from a lengthy manual procedure to a process lasting only a few minutes, while preserving the standardized state design of geological maps.

At the national level, these components are integrated within the Unified Geological Mapping Model of the Russian Federation and its continental shelf. The model will link digital representations of approximately 200 sheet-based sets of the 1:1,000,000-scale State Geological Map and approximately 1,100 sets at 1:200,000 scale with explanatory notes, archival geological materials, and systems of series legends. Since 2024, all work at 1:1,000,000 scale has shifted from individual sheets to the creation of a unified multidimensional geological coverage of Russia and its continental shelf, an area of approximately 19 million km². The platform provides a unified methodological framework, integration of multiscale geological data, formalized representation of geological objects, and coordinated monitoring of national map coverage.

The public and analytical layer of this architecture is the National Geological Mapping Resource 'Digital Twin of the Geology and Mineral Resources of Russia'. It brings together geological, tectonic, mineragenic, geochemical, geophysical, remote sensing, mineral-resource, licensing, exploration, and interpretation services in a familiar web-mapping environment. More than 250 map services can be combined as layers; users can query objects and calculate statistical indicators. A mobile version has

also been implemented. The same technological approach was applied for Cuban colleagues: in 2024–2025, a Digital Twin of Cuba's Subsurface was created jointly with the Cuban Institute of Geology and Paleontology, demonstrating that the architecture can be adapted to another national geological information environment. Since 2025, this approach has been applied to create the Digital Twin of the Subsurface of the Commonwealth of Independent States.

Artificial intelligence represents the next level of development. The Karpinsky Institute's Mente et Visione platform, currently under development, brings together several AI-oriented technologies: automated digitization of geological maps, diagrams, and cross-sections; recognition and structuring of scanned geological reports; AI-based identification of rocks and ores; analysis of explanatory notes and geological reports; forecasting of ore potential using empirical-statistical approaches; and automated boundary generalization when transitioning between scales. These applications are linked through a shared data repository, common data schemas, and a unified spatial key. The principal advantage of the approach is that AI methods operate on structured geological information and are embedded in actual geological production workflows rather than existing as isolated experimental solutions.

Together, these technologies form a modular digital chain extending from field observation to national geological synthesis. Individual components can be implemented independently; however, the greatest effect is achieved when field documentation, databases, cartographic standards, national geological models, web resources, and AI tools are interconnected. Experience from production-scale operation in Russia and adaptation for Cuba shows that the architecture can be transferred and configured to match the data structures, geological standards, and working practices of other geological surveys. For countries developing or modernizing national geological information systems, this provides a practical path towards a continuously updated digital geological environment that preserves geological meaning, data provenance, and methodological control of source information.

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Monitoring the border section of the State Geological Map of the Russian Federation at a scale of 1:1,000,000

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The Karpinsky Institute is the leading enterprise in the field of regional geological surveys of the Russian Federation and adjacent water area. The company has extensive experience compiling geological maps across a wide range of scales, from medium-scale (1:200,000) to summary maps and overview maps (1:2,500,000 – 1:5,000,000).

The 1:1,000,000 scale is the baseline for regional geological surveys in Russia. The third-generation State Geological Map of Russia and Adjacent Waters at a scale of 1:1,000,000 (GM-1000/3) is currently being finalized. Its content is significantly different from the previous version. The map is being compiled in digital format using extensive GIS technologies. Geological observations are accompanied by a range of modern analytical studies, and the final materials include an extensive database in digital formats. The map is being compiled by the Karpinsky Institute team and regional geological organizations across Russia. The Karpinsky Institute coordinates the work and provides methodological guidance.

The materials of the State Geological Map at a scale of 1:1,000,000 form the basis for summary maps of the territory of Russia and adjacent waters area at a scale of 1:2,500,000 (Geological Map, Map of Quaternary Formations, Tectonic Map, Forecast-Metallogenic Map, and others).

The organization of geological mapping at a scale of 1:1,000,000 involves compiling the map using individual sheets of the state grid measuring 6° in longitude and 4° in latitude. The territory of Russia is divided into 21 series of such sheets. Each series comprises 7-15 sheets and corresponds in area to a folded region, platform, or a significant parth of it.

A single legend is compiled for each series of GM-1000/3 sheets, ensuring consistency across sheet sets. The series legend contains:

- a tectonic zoning scheme at a scale of 1:2,500,000;
- a series of structural-formational zoning schemes based on event-age sections at a scale of 1:2,500,000;
- correlation schemes of pre-Quaternary and Quaternary formations;
- legends with characteristics of the mapped units (in matrix format);
- a mineragenic zoning scheme at a scale of 1:2,500,000 and a mineragenogram;
- schemes of geological, geophysical, and geochemical exploration at a scale of 1:2,500,000;
- explanatory notes and text appendices;
- other graphic and text materials.

Work on a specific sheet is preceded by the preparation of geophysical, geochemical, and remote sensing data at a scale of 1:1,000,000. For each sheet, a set of maps with legends and outline diagrams, an explanatory note, and an accompanying database are compiled in the format of a single GIS project. The set of 1:1,000,000 scale maps includes:

- Geological map;
- Map of mineral resources;
- Map of mineral resource distribution patterns and forecasts;
- Map of Quaternary formations;

- other specialized maps, the composition of which is determined by the specific geological structure, ecological state, and economic significance of the region.

The 1:2,500,000 scale out-of-frame schemes are represented by:

- Tectonic scheme;
- Geomorphological scheme;
- Mineral resource forecast scheme;
- Hydrogeological scheme;
- Ecological-geological scheme;
- Other schemes.

The 1:5,000,000 scale out-of-frame schemes are represented by:

- scheme of materials used;
- scheme of tectonic zoning;
- schemes of structural-formational zoning based on event-age sections;
- other schemes.

The accompanying database contains the following in digital formats:

- fact map (observation and sampling points);
- results of analytical studies;
- data on mineral deposits;
- information on the exploration status of the area, stratotypes, and petrotypes;
- geophysical, geochemical, and remote sensing bases at a scale of 1:1,000,000;
- primary geological documentation (field observation diaries, sampling logs, etc.)..

The explanatory note contains brief descriptions of the stratigraphic, igneous, and metamorphic units depicted on the geological map, information on the tectonic structure, mineral resources, hydrogeological and environmental conditions, and other information.

The creation of a set of state geological maps at a scale of 1:1,000,000 is accompanied by fieldwork, including visits, study, and sampling of key objects, as well as analytical studies of rocks and ores. The research is comprehensive, with an emphasis on studying the material composition and determining age. The Center for Isotope Research and the Central Laboratory of the Karpinsky Institute are equipped with modern laboratory equipment, allowing them to perform all the necessary analyses for solving problems related to geological mapping.

A sample list of analytical studies includes:

- silicate analysis (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, etc.);
- determination of trace and rare earth element contents;
- Sm-Nd and Rb-Sr isotope analyses (TIMS);
- preparation and description of transparent thin sections;
- microprobe analysis;
- etc.

Geochronological studies are conducted using the following methods:

- U-Pb dating (SIMS SHRIMP-II) of accessory zircon, titanite, and baddeleyite grains;
- U-Pb dating (LA ICP-MS) of zircon grains;
- Sm-Nd isochron dating of monomineral fractions and rocks;
- Rb-Sr isochron dating of monomineral fractions and rocks;
- Re-Os isochron dating of monomineral fractions and rocks.

The 100 km wide strip of the geological map bordering Mongolia on the Russian side includes 12 coordinated sheets of the State Geological Map at a scale of 1:1,000,000. They are part of the Altai-Sayan and Aldan-Transbaikal series. Sets of materials for these sheets were prepared in 2005-2008. Since 2020, the geological situation in this territory has been monitored, the sets have been supplemented and updated as new information on the geological, tectonic structure, minerals and metallogeny of the territory is received. The objects of geological mapping are stratigraphic units in the rank of suites, series and thickness, igneous and metamorphic complexes, provided for by serial legends. The geological map is accompanied by a tectonic map at a scale of 1:2,500,000 on a geodynamic basis and a tectonic zoning scheme at a scale of 1:5,000,000.

In 2025, Mongolian colleagues began compiling a geological map at a scale of 1:500,000 and a structural-tectonic map at a scale of 1:1,000,000 along the border with Russia. The Geological Task provides for linking them with the corresponding maps for Russian territory. A successful solution to this problem, in our opinion, is possible on the basis of a unified tectonic zoning scheme and a correlation scheme for geological units of border territories, prepared by the joint efforts of Russian and Mongolian geologists.

POSTERS

Contributions of the Mongolian–Soviet Joint Geological Expedition to the Study of Rare-Metal Granites in Mongolia

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The Mongolian-Soviet Joint Geological Expedition (1967–1986) was one of the most successful international geological programs conducted in Central Asia. During nearly two decades of collaborative research, the expedition established the geological framework of Mongolia through regional studies of stratigraphy, tectonics, magmatism, metamorphism, and metallogeny. The results were published in more than 50 monographs, hundreds of scientific papers, and numerous geological maps that remain important references today. Among its many achievements, the investigation of rare-metal granites occupies a special place. The expedition developed the first systematic classification of rare-metal granites in Mongolia, documented their spatial distribution, established their geochemical characteristics, and recognized their close relationship with rare-metal mineralization. These studies laid the foundation for modern investigations of Li-F granites, rare-metal magmatism, and associated ore systems. Here, we reassess the principal contributions of the Mongolian-Soviet Geological Expedition to the study of rare-metal granites in light of contemporary geodynamic models.

Geochemical Classification

One of the major achievements of the expedition was the systematic investigation of Mesozoic granitoid complexes distributed throughout Mongolia. Under the leadership of L.V. Tauson, and with major contributions from V.I. Kovalenko, M.I. Kuzmin, L.P. Zonenshain, V.S. Antipin, and A.V. Goreglyad, as well as Mongolian geologists including Ts. Tseden, Ts. Gundsambuu, S. Ariunbileg, O. Gerel, J. Lkhamsuren, B. Tumenbayar, and Sh. Batjargal, a comprehensive geochemical classification of granitic rocks and associated mineralization was developed. Based on petrographic, geochemical, and metallogenic characteristics, several types of rare-metal granites were distinguished, including standard granites (Modot type), Li-F granites (Sharhad type), and agpaitic granites (Dashbalbar type), together with their associated subvolcanic equivalents (Kovalenko et al., 1971; Tauson, 1977). The Janchivlan pluton represents one of the best examples, containing all three geochemical types within a single magmatic system. A particularly important contribution was the recognition that Li–F granites represent highly evolved magmatic products formed through extreme fractional crystallization of fluorine-rich melts rather than metasomatic “apogranites” as proposed by Beus et al. (1962). Geochemical and experimental studies demonstrated the critical role of fluorine in lowering melt viscosity and solidus temperatures, thereby facilitating advanced magmatic differentiation and enrichment of incompatible elements such as Li, Rb, Cs, Nb, Ta, Sn, W, and rare earth elements (REE). These findings established a genetic relationship among highly fractionated granites, pegmatites, greisens, and rare-metal mineralization. Subsequent discoveries of topaz-bearing, Li–F-rich volcanic and subvolcanic rocks, including ongonites and their analogues such as topaz rhyolites, elvans, and macusanites, further confirmed the broader significance of these magmatic systems.

Geological and Metallogenic Zoning

The expedition also documented regional-scale geochemical and metallogenic zoning in Mesozoic granitoid complexes of eastern Mongolia. The Khentei Batholith and associated Late Triassic-Early Jurassic plutons provide a notable example of such zoning. Less evolved quartz diorites and granodiorites typically occupy the central portions of the batholith, whereas highly evolved leucogranites and Li-F granites are concentrated in its marginal zones. A similar pattern is observed within individual plutons, where rare-metal granites commonly represent the youngest intrusive phases. This magmatic evolution is closely associated with rare-metal mineralization, which is preferentially concentrated in cupolas, dykes, aplites, pegmatites, and related hydrothermal systems. Greisenization and other late-stage hydrothermal processes further enhanced metal enrichment and ore formation

Geodynamic Significance

Although the original interpretations were developed within the framework of geosynclinal theory, the extensive geological dataset generated by the expedition provided the foundation for subsequent geodynamic reinterpretations. The acceptance of plate tectonic theory fundamentally changed the interpretation of granitoid magmatism in Mongolia, which is now understood in the context of the evolution of the Mongol–Okhotsk Orogen and the closure of the Mongol–Okhotsk Ocean. L. P. Zonenshain and co-workers were among the first to propose a plate-tectonic model for the Mongol-Okhotsk belt, suggesting a scissor-like closure of the ocean and drawing comparisons with Andean- and Californian-type tectonic settings (Zonenshain et al., 1990). In current geodynamic models, rare-metal granites are generally interpreted to have formed in post-collisional extensional settings characterized by lithospheric thinning, mantle-derived heat input, crustal anatexis, and prolonged magmatic differentiation. Li–F rare metal granites represent the most highly evolved products of these magmatic systems and are closely associated with rare-metal mineralization.

Future Perspectives

Recent advances in analytical methods, including U–Pb zircon geochronology, Sr–Nd–Hf isotope geochemistry, and in situ trace-element analysis, have significantly improved understanding of the petrogenesis and metallogeny of rare-metal granitoids. These studies indicate complex magma sources involving varying contributions from continental crust, mantle-derived components, and extensive fractional crystallization. Modern investigations increasingly integrate geochemical, isotopic, and geodynamic data to constrain the timing and mechanisms of rare-metal mineralization. Recent studies (e.g., Yarmolyuk et al., 2013; Dostal et al., 2015; Antipin et al., 2016, 2022) have refined earlier models while confirming many of the fundamental concepts established by the Mongolian-Soviet Geological Expedition. In addition to its scientific achievements, the expedition made a lasting contribution to the development of Mongolian geosciences by training a generation of geologists and fostering long-term international scientific collaboration. Its legacy continues to shape contemporary research and exploration strategies, particularly in the context of the growing global demand for critical metals such as Li, Nb, Ta, and rare earth elements (REE).

Conclusion

The Mongolian-Soviet Joint Geological Expedition established the first comprehensive framework for understanding rare-metal granitoids in Mongolia. Its geological, petrological, geochemical, and metallogenic investigations remain fundamental references for modern studies of granitoid magmatism and rare-metal mineralization. Contemporary analytical approaches continue to refine these concepts, demonstrating the enduring scientific value of the expedition's contributions to the geology and metallogeny of Central Asia.

Quantitative Paleomagnetic Constraints on the Permian Evolution of the Eastern Paleo-Asian Ocean

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The Central Asian Orogenic Belt (CAOB) is the largest Phanerozoic accretionary orogen on Earth, whose architecture is fundamentally linked to the closure of the Paleo-Asian Ocean (PAO). While it is widely accepted that the western PAO closed earlier than its eastern counterpart, the precise paleogeographic and kinematic evolution of the eastern domain remains controversial. By the Late Paleozoic, the eastern PAO comprised two major branches: the northern Hegenshan Ocean and the southern Solonker Ocean. However, significant debate persists over which branch represented the premier oceanic basin during the Permian, primarily due to a lack of quantitative paleolatitudinal constraints on the intervening core tectonic unit—the Mongolia Block (MOB). Here, we present integrated high-quality paleomagnetic and geochronological data from Early Permian volcanic sequences of the MOB, yielding reliable paleomagnetic poles at ~298 Ma and ~283 Ma. These results allow us to reconstruct a robust Carboniferous–Permian paleolatitudinal drift trajectory for the block. By combining our new paleomagnetic constraints with the apparent polar wander paths of the adjacent Xilinhot-Songliao and North China blocks, along with multidisciplinary evidence from sedimentology, paleontological biogeography, and magmatism, we demonstrate that the Hegenshan Ocean was the premier basin of the eastern PAO during the Early Permian, spanning a north–south width of ~2000 km. Furthermore, our quantitative kinematic reconstructions reveal that the Hegenshan and Solonker oceans closed almost synchronously during the Late Permian to Early Triassic (~250 Ma). This synchronous closure marks the terminal demise of the PAO and the establishment of the final paleogeographic framework of the CAOB.

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Tectonic relationships of the Trans-Altai Zone and its connection to the Mongolian Altai Orogenic Belt: Implications for Paleozoic geodynamics of the Central Asian Orogenic Belt.

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This study presents a comprehensive whole-rock geochemical analysis of greywacke-type sediments from the Khuvinkhar and Nemegt Subzones of the Trans-Altai Zone (TAZ). It includes U-Pb geochronological investigations of detrital zircons, alongside a detailed examination of structural and regional metamorphic records within these subzones. The Permian–Triassic D2 deformation has been documented in both the Khuvinkhar and Nemegt Subzones; however, only the Nemegt Subzone exhibits evidence of metamorphism that occurred prior to D2. The greywacke and lithic tuffaceous sandstone found in these subzones indicate a proximal source, with Chemical Index of Alteration (CIA = 45–55). In the Khuvinkhar Subzone, the geological formations display a tectonic contact with the lower Ordovician litharenite (ca. 475 Ma) to the north. This suggests that the boundary between the Mongolia Altai Zone (MAZ) and TAZ reflects intracontinental deformation rather than characteristics commonly associated with a suture zone. Geochemical variations, particularly in the Ti/Zr and La/Sc ratios, indicate that the greywackes in the Nemegt Subzone are likely derived from an oceanic island arc, while those in the Khuvinkhar Subzone appear to be sourced from a continental arc. Notably, sediments from both subzones are characterized by low concentrations of High-Field-Strength Elements (HFSE, Ta, Nb, Ti). Based on recent findings and previously reported deep oceanic complexes within the TAZ, it is reasonable to propose that the southern part of the TAZ may correlate with a supra-subduction environment. The sediments within the Nemegt Subzone are believed to have been deposited in a back-arc basin, bearing similarities to the Baaran Subzone of the Taz and Dulate domains in East Junggar. Conversely, the sediments found in Khuvinkhar are likely influenced by an active marginal geotectonic setting. The results of U-Pb isotopic dating on detrital zircons indicate that the sediments from both subzones were deposited during the Mississippian to lower Permian period (ca. 297–348 Ma). The primary source of these sediments is the MAZ located to the north. However, the youngest or predominant detrital zircon population highlights a syn-arc sedimentation relationship with the Carboniferous volcanic arc and its associated sources. Subsequently, the amalgamation of the Devonian-Carboniferous back-arc and the Carboniferous magmatic arc occurred due to significant shortening during the Permian-Triassic period, leading to the formation of the current geological structure. The initial epsilon Hf values (ranging from −1.7 to +15.2; THf DM.2stg = 1.1–0.4 Ga) demonstrate a strong correlation with the volcanic rocks present in the TAZ as well as the sediments found in the Dulate domain, which is linked to the Carboniferous back-arc basin. In conclusion, it is evident that the TAZ displays a robust geological and geodynamic relationship with the MAZ to the north. Furthermore, both the TAZ and Dulate domain exhibit comparable lithological, geochemical, and isotopic characteristics, warranting a close correlation. Therefore, it can be posited that the TAZ extends westward into East Junggar and shares a similar geotectonic evolutionary history.

Stratigraphy, palaeontology and sedimentology of the Mesozoic formations in the Shiliin Nuruu Syncline (Gobi Altai, Mongolia)

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The presented geological map at a scale of 1:75,000 represents a part of the Upper Mesozoic sedimentary belt, which is exposed along the northern slopes of the Mongolian Altai in the Valley of Lakes (Western Mongolia). This map is based on the reinterpretation of field,sedimentological, petrological, and paleontological data collected in the area during a regional geological mapping conducted here by the Czech Geological Survey between 2004 and 2006.The Upper Jurassic to Lower Cretaceous formations of the Shiliin Nuruu Syncline, which have both lateral and vertical transitions, reach a total thickness of up to 1000 m. Poorly sorted conglomerates and breccias in the bottom of the sequence represent the proximal parts of the alluvial fans and grade up to the cycles of sandstones, mudstones, siltstones, marls, and local coal seams of fluvial to lacustrine origin. Rocks contain relics of terrestrial plants indicating a rather warm climate. The coalification corresponds to early brown coal. The rich Hauterivian–Aptian palaeontological association containing conchostracans, larvae of giant mayflies, gastropods, bivalves, and fish in the Anday Khudag and the Khulsan Gol formations could be compared with the Jehol Biota in northeast China.

Sedimentary record of oroclinal collision and ocean closure, Buregkhangai basin of the Mongol-Okhotsk suture zone in northern Mongolia

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The Mongol-Okhotsk Belt (MOB) extends from central Mongolia northeastward to the Sea of Okhotsk, and marks the boundary between the stable Siberian craton and accreted Phanerozoic terranes of the Central Asian Orogenic Belt. Remarkably little is known about this fundamental tectonic boundary: interpretations of its location, timing and mechanisms of formation, and paleogeography are debated. End-member models invoke major oroclinal bending along a large continuous margin, to scissor-like closure of a much smaller backarc basin. Recent geochronological, structural, paleomagnetic and sedimentary data collected by our group and others are key for testing the predictions of these models and considering other geodynamic processes such as slab rollback and slab break-off.

Here, we use the understudied stratigraphic record from the Buregkhangai Basin (Fig. 1)—the largest Triassic depocenter in northern Mongolia—to investigate sedimentary basin evolution, provenance, and subsidence mechanisms during the Permian-Triassic in the western MOB. The depocenter is located on the northern limb of the inferred oroclinal hinge, and north of Paleozoic accretionary deposits exposed along the axis of the MOB. It is filled by an overall upward-coarsening fluvial and alluvial sequence of the Avzaga Formation, that is up to ca. 5 km thick. Interbedded multi-modal volcanic units in the lower Avzaga section have zircon U-Pb ages of ~228-234 Ma, which corresponds with youngest single grain ages from detrital zircons, indicating Late Triassic (Carnian)-aged deposition. The Triassic section is entirely nonmarine, and unconformably overlies marine Carboniferous strata (Urmugtei Formation) in the area, suggesting that these two sections record pre- and post-ocean closure deposition.

Detrital zircon U-Pb data from the basin deposits have prominent Carboniferous (~341-346 Ma), late Permian (~253-256 Ma), and Late Triassic (~232-237 Ma) peaks, along with subordinate Devonian through Cambrian-Ordovician distributions. Clast counts from cobble conglomerates abundant on the western side of the basin are dominated by sedimentary lithologies, including a distinctive red chert that likely correlates with Devonian cherts mapped and observed south of the basin, and show an increase in igneous sources up section. Inferred source areas include Paleozoic strata and Permian arc volcanics, both widely exposed around the basin, though we infer that primary deposition was from the south/southwest.

Thus, our analysis suggests that this Late Triassic nonmarine depocenter is sourced by Paleozoic arc and basin deposits exhumed within the Tuva–Mongol orocline and by Early Triassic volcanic rocks formed during and after closure of the Mongol–Okhotsk Ocean. Nevertheless, subsidence mechanisms for the Triassic strata in the Buregkhangai basin are enigmatic. Classical collisional basin and remnant ocean basin models do not fully explain such thick late- to post-collisional stratigraphic sequences with interbedded volcanics, plus accompanying structural data indicating regional strike-slip deformation. We suggest that wrench tectonics and transtensional subsidence, driven by oroclinal closure, also provides a possible explanation for such thick, localized deposits formed near the oroclinal hinge. The additional role of slab mechanics such as rollback or break-off, along with possible mantle plume

initiation, must also be considered, particularly as an explanation of thick LateTriassic-Early Jurassic volcanics (Mogod Formation) in the area.

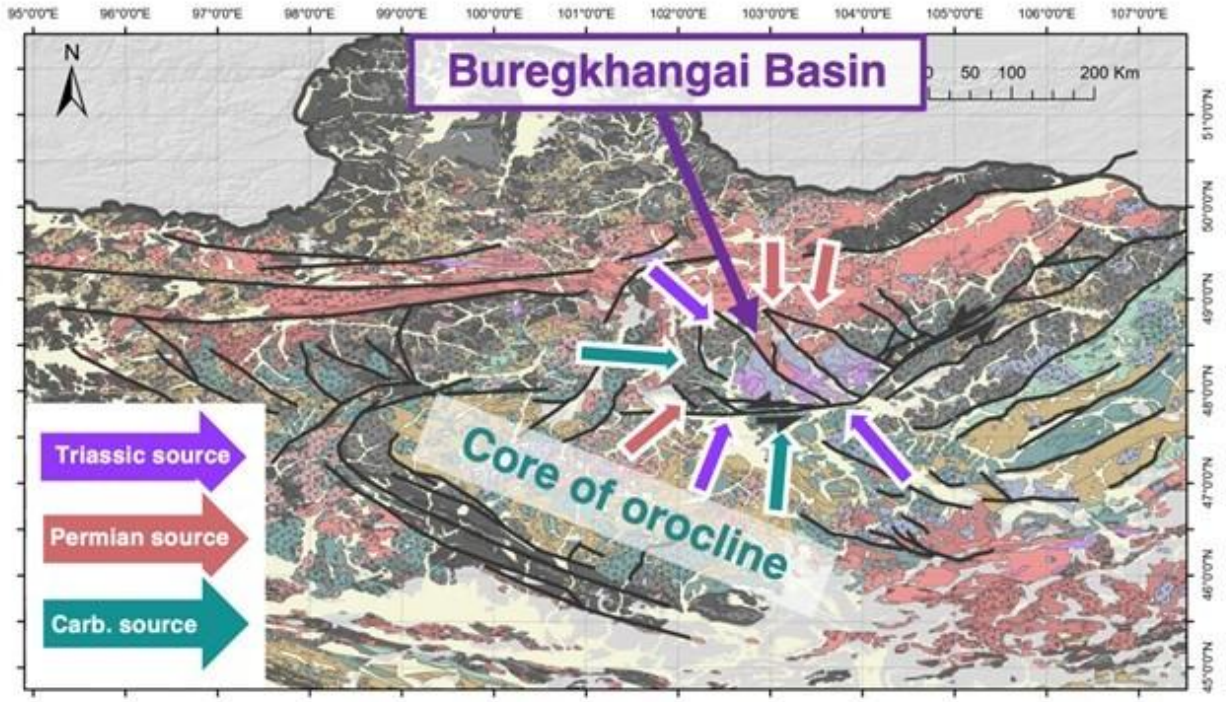


Figure 1: Location map of the Buregkhangai basin and surrounding areas. Arrows indicate source areas for the basin.

Results of Heavy Mineral Panning Studies of Placer Sediments from the Khasagt Region, Zavkhan Terrane, Mongolia

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This study presents the results of heavy-mineral panning investigations of placer sediments from the Khasagt region of the Zavkhan Terrane, Mongolia. A total of 66 samples were collected from lateral and mid-channel bars within two exploration areas: Area A, associated with gold-bearing quartz veins and Cu sulphide mineralization, and Area B, characterized by magmatic Ti–V–Sc mineralization hosted by a gabbroic massif. The samples were sieved, manually panned, divided into grain-size classes, and separated into magnetic and non-magnetic fractions. Mineral identification was conducted using polarizing and stereoscopic microscopy, while placer-gold grains were counted and analysed in terms of size, morphology, roundness, flatness, and surface microstructures.

The heavy-mineral assemblages show considerable spatial variability. Pyroxene, amphibole, magnetite, and ilmenite account for approximately 90% of the concentrates, whereas zircon, epidote, chlorite, leucoxene, garnet, kyanite, andalusite, rutile, spinel, staurolite, topaz, tourmaline, goethite, and hematite occur as subordinate or accessory phases. Placer gold was recorded exclusively in Area A, with concentrations ranging from 0 to 33 grains per sample and up to approximately 5.4 g/m³. Most grains are fine- to medium-grained, predominantly within the 0.26–0.75 mm interval. Nearly 83% represent irregular cementation–aggregate forms, while subangular and subrounded grains constitute 89.2% of the population. Flatness indices are mainly below 10, and some grains preserve primary mineral inclusions.

The morphological characteristics of the gold, together with the petrographic composition of the concentrates, indicate short transport over distances of several kilometres and a predominantly local source. The most probable primary sources are nearby mineralized quartz veins associated with intensely fractured and sheared zones within an ophiolitic dyke complex. The results confirm the usefulness of heavy-mineral panning and gold-grain morphology in tracing local mineralization and identifying prospective areas for further exploration.

Keywords: heavy minerals, placer gold, panning concentrates, gold-grain morphology, mineral exploration, Khasagt region, Zavkhan Terrane, Mongolia

Late Pleistocene and Holocene Paleoclimate records from sediments of Achit Lake, Western Mongolia

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Key words: Achit Lake, major elements, Chemical Index of Alteration (CIA), climate change

This paper makes an attempt to reconstruct the paleoclimate changes of western Mongolia in Late Pleistocene and Holocene based on the results of distribution of major elements studies on the gravity cores, obtained from the Achit Lake. Achit Lake (49°30'N, 90°36'E) is the largest freshwater lake in the Uvs Aimag (province) of Mongolia, in the west of the country. It is between Kharkhiraa Uul and Turgen Uul, at an elevation of 1435 m above sea level it covers an area of 296,8 km². It is 24 km long, 18 km wide and 10 m deep (Tserensodnom, 2000). The coast is covered with steppes, mostly hilly but swampy on the northwest and northeast. Several rivers such as the Tsagaan, Khatuugiin, Bukhmurun and Uliastai rivers flow into the lake. The lake was probably formed by tectonic processes in the middle Pleistocene (Dorofeyuk, 1988). Achit-Lake has low, swampy northern and southern shores with salt-marsh vegetation, and high eastern and western shores, formed by granite rock and covered by desert steppe vegetation. Macrophyte vegetation is widespread in the shallow zone (Dorofeyuk, 1988).

In this study, we investigated lithological, geochemical and some major elements distribution of the core sediments and determined Chemical Index of Alteration (CIA) on the ratio of elements of the core. The core Achit 2010-3(N49º25'19''; E93º31'43'') was obtained during the Chinese-Mongolian expedition. The core Achit 2010-3 with length of 200 cm, water depth of 3,8 m was cut lengthwise and after the lithological description has been sub-sampled into 2 cm intervals for major and micro element analysis. These elements were determined by X-ray Fluorescence (XRF) in laboratory of Mongolian University of Science and Technology (MUST). According to the visual description, the sediment of the core Achit 2010-3 consists of 3 main lithological units from bottom to the top (Fig1).

Sediment unit 1(199-180cm) is clay (10YR6/2). At intervals of 157-141 cm is gray (7.5Y6/1), at 122-0 cm yellow brown (2.5Y6/2) clay layer. At intervals of 157-141.5 cm contains plant and numerous shells.

Sediment unit II (180-157cm) consists of dark grey clayey silt. The layer contains fine to medium grained sandy layer (5Y6/1). Sediment unit III (141.5-112 cm) is sandy layer. At intervals of 128.5 см, 130 см, 132.5 cm plant remains, at intervals of 133 cm mollusk shells.

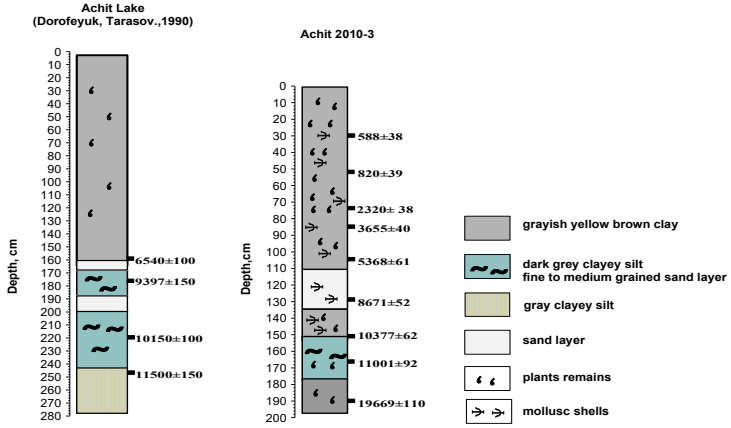


Figure 1. Lithology and chronology of cores from Lake Achit.

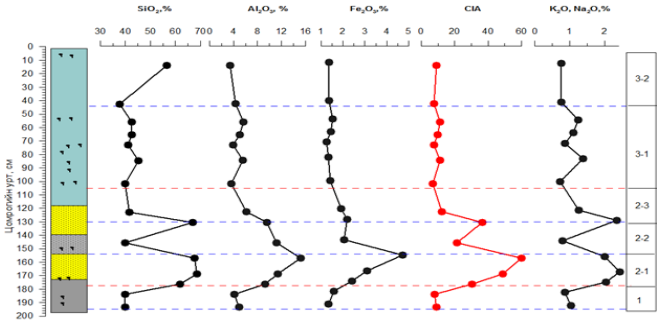


Figure 2. Distribution and element contents and Chemical Index of Alteration.

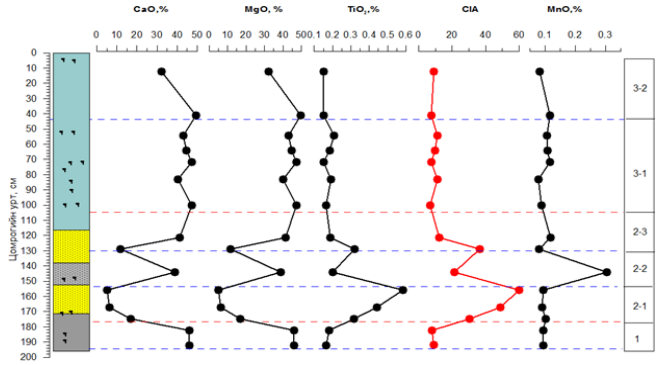


Figure 3. Distribution and element contents and Chemical Index of Alteration.

In the sediments of Achit Lake, the contents of following oxides varied: SiO_2: 37.77-68.54%; Al_2O_3-3.38-15.18%; Fe_2O_3-1.26-4.71%; TiO_2-0.15-0.58%; MnO-0.08-0.30%; CaO-4.97-49.5%; MgO-1.19-3.62%; Na_2O-0.72-2.44%; K_2O-0.83-3.16%; P_2O_5-0.07-0.14%.

The high contents of oxides such as SiO_2, Al_2O_3, TiO_2, Fe_2O_3, K_2O and Na_2O associated with active layers of Chemical Index of Alteration (CIA) and corresponding of two dry climates: from ~13.200 to ~6400 cal BP and from ~1600 to 0 cal BP (Aizhi Sun., 2013). But high contents of MgO, CaO associated with inert layers of Chemical Index of Alteration and corresponding two wet periods: from ~22,600 to ~13,200 cal BP and from ~6400 to ~1600 cal BP. So, the elements of Achit Lake and the processes of CIA controlled the climate change of late Pleistocene and Holocene.

Conclusions

Lithological and geochemical study of Achit Lake leads to the following conclusions.

- The sediment of the lake Achit consists of 3 main lithological units from bottom to the top. Unit 1 is grayish yellow brown clay with contains plant and shells. Unit 2 consists of dark grey clayey silt with sand layer. Unit 3 a generally yellow brown clay layer.
- Concentrations of macro elements of the core from Achit Lake during the Holocene is relatively stable. Distribution of calcium and magnesium oxides are inverse with silicon and sodium and potassium oxides unit 1 and 2. Profiles of aluminum, iron and titanium oxides are positively correlated with each other.
- The high contents of oxides such as SiO_2, Al_2O_3, TiO_2, Fe_2O_3, K_2O and Na_2O associated with active layers of Chemical Index of Alteration (CIA) and corresponding of two dry climates: from ~13.200 to ~6400 cal BP and from ~1600 to 0 cal BP (Aizhi Sun., 2013). But high contents of MgO, CaO associated with inert layers of Chemical Index of Alteration and corresponding two wet periods: from ~22,600 to ~13,200 cal BP and from ~6400 to ~1600 cal BP. So, the elements of Achit Lake and the processes of CIA controlled the climate change of late Pleistocene and Holocene.

Tectonic and climatic controls on Late Quaternary lacustrine sedimentation in arid Central Asia: evidence from Olgoy Lake, Mongolia

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Keywords: Olgoy Lake, Late Quaternary, neotectonics, Khangai Mountains, multi-proxy analysis

Closed-basin lakes in arid Central Asia are sensitive archives of environmental change, but in deforming terrain accommodation space and drainage are set by tectonics, the infill by climate. Olgoy Lake (2041 m a.s.l., ~1.55 km^2, ~1 m deep, no inflow or outflow) occupies a small closed basin on the southern flank of the Khangai Mountains. It formed by late Quaternary uplift along the Bayankhongor fault, and its catchment was repeatedly glaciated during Marine Isotope Stages (MIS) 3 and 2 — a rare chance to separate tectonic from climatic controls in southern Mongolia, where records beyond the Holocene are scarce.

Core OLG17-02 (10.5 m) was recovered from the lake centre in 2017 through the frozen surface. Eighteen elements were measured at 0.5 mm resolution by ITRAX XRF scanning, sediment properties at 2 cm intervals (n = 525) and mineral assemblages by XRD. Chronology combines 17 ^{14}C ages on plant remains, shells and bulk organic carbon with OSL and IRSL ages in a Bayesian (IntCal20) age–depth model; six outliers (probability $\geq$ 0.5) were rejected and the accepted model spans ~4–51 cal ka BP.

Six lithological units are recognized, and factor analysis resolves three factors (67% of variance): F1 (27%; Ca–Sr–Mn–carbonate), authigenic productivity and evaporative carbonate precipitation; F2 (18%; Al–Si–K–Ti–Fe–Rb), terrigenous detrital input; F3 (21%; S–Zr–water–grain size), Khangai meltwater and permafrost-thaw input. Sulfur is enriched at ~11–16, ~25–38 and ~40–48 cal ka BP. Superimposed on these trends are six coarse-clastic horizons with sharp basal contacts and abrupt coarsening (EV-04 to EV-09; 245–992 cm), with no counterpart in the authigenic proxies; we read them as discrete neotectonic events on the Bayankhongor fault.

MIS 3 (~51–28 cal ka BP) was not uniformly cold in the Khangai: coarse clastic units with elevated S, Fe and Mn and high F3 loadings record meltwater and permafrost-thaw pulses released during interstadials between glacial advances, sustaining high lake levels. MIS 2 contrasts sharply — near the local Last Glacial Maximum (~20 cal ka BP) authigenic carbonate peaks while terrigenous input drops, indicating a shrunken, evaporative lake. A dry phase near the Younger Dryas (~13 cal ka BP) precedes stable Holocene sedimentation with a brief mid-Holocene (~7–5 ka) authigenic phase. OLG17-02 is thus one of the longest continuous Late Quaternary records from southern Mongolia, and shows that tectonic and climatic forcing must be separated where lake fills in deforming terrain are used as palaeoclimate archives.

Petrogenesis of a Late Paleozoic arc-related layered ultramafic-mafic intrusion in northern Mongolia: Preliminary stratigraphic and geochemical constraints

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Keywords: layered intrusion; ultramafic-mafic plutonic rocks, cumulate stratigraphy, arc magmatism, northern Mongolia

The study of layered intrusions at convergent margins is critical for advancing our understanding of arc-crust evolution. This research focuses on the cumulate stratigraphy, macro-textures, and whole-rock geochemistry of well-exposed Late Paleozoic layered ultramafic-mafic plutonic rocks located in northern Mongolia. Field observations indicate a systematically fractionated hydrous magmatic sequence. The basal ultramafic cumulates, comprised of plagioclase bearing peridotite and harzburgite, pass upward into mafic cumulate zones characterized by olivine-rich gabbroic cumulates. Progressing to upper structural levels, the sequence shifts to amphibole gabbros and a predominantly plagioclase-rich leucogabbro, which features macro-scale mafic microgranular enclaves with distinct boundaries, suggesting significant thermal and rheological contrasts. The upward transition into amphibole-rich gabbros is consistent with increasingly hydrous magma conditions during fractional crystallization. Studied samples preserve a record of a dynamic arc-related hydrous melt system, progressing from likely primary fractional crystallization to sequential high and low-temperature fluid overprinting. For instance, the primary cumulate framework of olivine, pyroxene, and chromian spinel crystallized from a volatile-rich subduction magma that systematically delayed plagioclase saturation to late-stage intercumulus domains. As fractionation advanced, volatile enrichment within the residual melt triggered an intensive phase of metasomatism, resulting in the pervasive reactive replacement of both primary pyroxene and olivine by late-magmatic amphibole. Following chamber consolidation, lower-temperature fluid infiltration initiated secondary serpentinization within remaining olivine cores, developing characteristic mesh-textures. Geochemical analyses indicate a subduction-related framework, with all samples plotting within the active continental margin field on the Ti/V tectonic discrimination diagram. Chondrite-normalized rare earth element patterns exhibit low REE concentrations and a prominent positive Eu anomaly, consistent with the accumulation of plagioclase cumulus. The primitive-mantle-normalized trace element spider diagrams illustrate characteristic signatures of volcanic arcs. These diagrams indicate a significant enrichment in large-ion lithophile elements (LILE; Cs, Ba, K, and Sr) In addition, there are pronounced negative anomalies observed in High-Field-Strength Elements (HFSE, Nb and Zr. Notably, there is a distinct negative Nb anomaly accompanied by a marked positive Pb anomaly. Overall, these findings elucidate a multi-stage history involving gravitational crystal accumulation, volatile influence during magma evolution mechanical mingling, driven by a subduction-derived parental melt. In summary, these findings provide structural and geochemical evidence of primitive arc magma reservoirs, emphasizing the dynamic processes of mass, heat, and volatile transfer within an Late Paleozoic subduction system influenced by the evolution of the Mongol-Okhotsk Ocean. Ultimately, this research demonstrates that volatile-influenced fractional crystallization and mechanical mingling within deep sub-arc reservoirs play a important role in the compositional differentiation, maturation, and growth of convergent margin continental crust.

Plume-related mid-Devonian–Carboniferous magmatism along the Paleo-Pacific active margin – Gashun Nuur Complex, Mongolian Altai

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Keywords: Big mantle wedge; Hydrous plume; Slab rollback; Back-arc extension; Peripheral continental growth; Bodonch–Tseel Zone

The Mongolian Altai accretionary wedge (AAW) was an immense early Palaeozoic fore-arc volcano-sedimentary basin (Jiang et al., 2011; Soejono et al., 2017) reworked into a layered continental crust in Devonian times (Hanžl et al., 2016). Even though Devonian mafic magmatic complexes intruded into the AAW surrounding Lake Gashun Nuur (Tseel sum, Mongolian Altai; Kozakov et al. 2019), the role of mantle-derived melts during this major tectonic event remains elusive. We bring new petrological observations, whole-rock geochemical and Sr–Nd isotopic data, and zircon U–Pb ages from the Gashun Nuur Complex (GNC) that constrain the role of the mantle in stabilising the Mongolian Altai continental crust (de Hoÿm de Marien et al., 2025).

Mafic rocks of the GNC occur as scattered hectometre-sized bodies and as widespread meter-thick sheets. The large bodies are (meta)gabbroic boudins wrapped in the regional migmatitic foliation; likewise, the (meta)basalt–(meta)dolerite sheets (hereforth referred to as amphibolites) are concordant with this foliation. All the samples contain predominantly amphibole and plagioclase, and some sheets also contain garnet. Replacement textures indicate a metamorphic overprint. Yet, most rocks contain relics of magmatic amphibole, and the metagabbros with some sheets still preserve pristine magmatic cumulate textures.

Zircon U–Pb geochronology constrains the emplacement ages to the mid Devonian (c. 385 Ma) for the large bodies, and to the late Devonian to early Carboniferous for the amphibolite sheets (c. 377–350 Ma). Likewise, zircon U–Pb data from the host migmatite support a coeval partial melting (c. 375–360 Ma). Primary amphibole chemistry suggests a water-rich (6–12 wt%), relatively low-temperature (700–900 °C) melt, and a wide range of emplacement pressures (1–8 kbar). In the Mongolian Altai, extensional tectonics occurred in the Devonian (Buriánek et al., 2022). Yet, the highest pressures recorded in the garnet-bearing GNC sheets suggest that the local crust was not significantly thinned.

The early metagabbroic bodies are enriched in Large-Ion Lithophile Elements (LILE; Th_N = 2.3–16.2) and feature variably deep troughs in High Field Strength Elements (HFSE; Nb/Nb* = 0.61–0.14). They carry radiogenic Nd (ε_{Nd}^{i} of +7.0 to +3.9), indicating a depleted mantle source. Importantly, the least evolved Nd isotopes are preserved in the geochemically most primitive samples (Mg# up to 83.6). This, together with an unradiogenic signature of Sr isotopes ($^{87}Sr/^{86}Sr_i$ of 0.7036–0.7044), rules out significant crustal contamination *en route* to the surface and rather supports an interaction of two source components: ascending asthenospheric mantle and local lithospheric mantle with a subduction imprint.

The younger amphibolite sheets are also enriched in LILE (Th_N = 0.5–15.2) but HFSE anomalies are more variable to non-existent (Nb/Nb* = 0.27–1.09). In turn, their trace-element spidergrams are intermediate between those of the large bodies and the canonical EMORB. They also display positive ε_{Nd}^{i} values of +9.2 to +6.4, but contrast with the large bodies by having a more variable Sr isotopic signature, extending toward more radiogenic values ($^{87}Sr/^{86}Sr_i$ of 0.7037–0.7068). Besides the two mantle sources mentioned above, this implies a variable role for contamination by immature AAW crust, or its melts.

Taken together, all the available data from the Gashun Nuur Complex are understood in terms of an interaction between a subduction-modified depleted lithospheric mantle and a mantle plume far behind an active magmatic arc. The magmatic complex studied was coeval with intracontinental magmatism of the so-called Altai–Sayan large igneous province (LIP), located even farther away from the Devonian volcanic arc (e.g. Vorontsov et al., 2021). A trend visible in several geochemical proxies from the Altai–Sayan LIP to the Gashun Nuur Complex suggests a close genetic link between the two. Critically, the distinct belts are parallel to each other and to the Devonian volcanic arc, suggesting that the geometry of the active margin controlled the distribution of the magmatic provinces behind the arc.

In this context, and in agreement with previous studies (Cui et al., 2024), we interpret the Devonian magmatic event as the surface expression of arriving hydrous plume(s) developed above a dehydrating flat slab resting atop the lower mantle, at the mantle transition zone (MTZ). The interaction between the slab and the MTZ favoured slab rollback and trench retreat, causing extension in the overriding lithosphere. Heat and fluids from mantle-derived intrusions induced extensive partial melting of the fertile Cambrian–Ordovician AAW, promoting a wide-rift mode of extension and avoiding significant crustal necking. Ascending granitic magmas (Burenjargal et al., 2016) left a residual, partially dehydrated lower crust, likely of intermediate composition. This crustal differentiation process not only contributed to the peripheral growth of the Siberian Continent but also potentially played an important role in the stratification and stabilisation of the continental crust throughout the Earth's history.

Acknowledgements

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Permian syn-extensional Barrovian metamorphism in the Mongolian Altai

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Keywords: Petrochronology; Barrovian metamorphism, Contact metamorphism; lithosphere-scale extension

A Barrovian-type metamorphic sequence is widely recognised throughout the Palaeozoic Altai orogenic belt, where it marks the transition between exhumed lower- and upper-crustal domains. It is considered the product of a Carboniferous crustal thickening event and ensuing thermal maturation (Kozakov et al., 2011; Sukhorukov et al., 2016). We re-examined this metamorphic sequence along the River Gegetin–Gol using integrated field and petrologic observations, phase equilibria modelling, U–Pb zircon LA-ICP-MS geochronology, and in-context U–Pb monazite LASS geochronology (Hoÿm de Marien et al., 2026).

The Barrovian metamorphic zonation is sharp, extending over less than 5 km from the biotite to the sillimanite zones. It is localised across an extensional shear zone recognised by strain gradients, mylonites, and the apparent sense of shear of passive folds. Shearing is Permian as indicated by the age of syn-tectonic dykes at c. 295–290 Ma (U–Pb zircon). Micaschist occurs in the hangingwall of the shear zone where garnet and staurolite increase in size within the neck zones of boudinaged quartz veins, indicating syntectonic growth. A mineral sequence indicates three metamorphic stages: $M1_{mic}$ marked by garnet 1-chlorite, $M2_{Mic}$ indicated by garnet 2-staurolite or garnet 2-staurolite-kyanite, and $M3_{mic}$ characterised by sillimanite. According to phase equilibria modelling, M1 correspond to a pressure and temperature increase from 525–550 °C and 3–4 kbar to 550–575 °C and 5–6 kbar; M2 indicates an isobaric heating from 550–575 °C to 625–680 °C at ~7 kbar, and M3 is related to a decompression below 6 kbar. The pressure increase during $M1_{Mic}$ was likely associated with Carboniferous crustal thickening as suggested by U–Pb dating of monazite included in garnet 1 (c. 350–340 Ma). However, the staurolite-bearing assemblages are related to isobaric heating poorly compatible with crustal thickening. Moreover, the monazite crystals associated with garnet 2, staurolite, and sillimanite ($M2_{Mic}$ and $M3_{Mic}$) consistently yield Permian dates (c. 290–285 Ma), coeval with the activity of the extensional shear zone. Staurolite porphyroblasts contain inclusions marking an internal fabric continuous with the main matrix foliation, itself wrapping around the porphyroblasts. Sillimanite replacing staurolite is also oriented within the matrix fabric. Hence, the microtextures confirm the syntectonic character of $M2_{Mic}$ and $M3_{Mic}$ with respect to the extensional foliation. This demonstrates that, rather than the results of the Carboniferous crustal thickening event, the staurolite and staurolite-kyanite assemblages often seen as diagnostic of the Barrovian metamorphism are syntectonic with respect to the Permian extension.

The extensional foliation is grading downward into the migmatitic foliation in the shear zone footwall. In a migmatite, anhedral garnet cores document a prograde metamorphic stage ($M1_{Mig}$), which remains

poorly constrained. The garnet rim, together with resorbed kyanite ($M2_{Mig}$) and euhedral sillimanite ($M3_{Mig}$), documents an isothermal decompression from 9 to 4–7 kbar at a high temperature of ~750 °C. Crystallisation of the interstitial melt implies subsequent cooling below 700 °C. Regardless of the textural association with kyanite ($M2_{Mig}$) or sillimanite ($M3_{Mig}$), monazite crystals systematically yield Permian dates (c. 285 Ma), interpreted as the age of decompression. Exhumation of the lower crustal migmatite was therefore coeval with the syntectonic magmatism focused in the extensional shear zone and with the Barrovian metamorphism of its hangingwall.

These relations suggest that isobaric heating of the micaschist is a consequence of heat redistribution during the exhumation of the migmatite and the associated magmatism. We concur, therefore, with previous studies' conclusions that crustal thickening is not the main and only tectonic setting for the development of Barrovian metamorphic conditions (e.g. Viete et al., 2011; Ryan and Dewey, 2019). In addition, we propose that the mid-crustal envelope of extensional migmatite domes related to crustal thinning represents a favourable tectonic setting for the development of the Barrovian mineral sequence.

Acknowledgements

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Ediacaran magmatic arc at the northeastern margin of the Baidrag microcontinent: Whole-rock geochemistry, Sr-Nd and zircon U-Pb isotopic results

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Keywords: Baidrag Block, Bayankhongor Ophiolite, Magmatic Arc, Southwestern Mongolia

This study analyzes the origin and crystallization age of intrusive magmatic rocks, both acidic and basic, around Unegt Mountain on the northeastern margin of the Baidrag microcontinent. The studied samples are classified as gabbro to granite rocks based on their major element compositions and fall within the calc-alkaline series. These igneous rocks are characterized by depletion in High Field Strength Elements (HFSE: Ta, Nb, Zr, Hf, Ti) and an enrichment of Th, indicating their formation in an active continental margin or a subduction-related geotectonic environment. The gabbro sample exhibited a positive initial εNd(t) value of +10.82, suggesting a mantle-derived source, while granites show initial εNd(t) values ranging from −9.09 to +0.15, implying variable degrees of crustal contamination. Zircon U-Pb geochronology indicates that these rocks crystallized during the Ediacaran (ca. 601–550 Ma). Taken together, these results suggest the development of an active continental margin in the northeastern part of the Baidrag microcontinent during the Late Neoproterozoic. This active margin is believed to have formed as a result of the subduction of the Bayankhongor oceanic crust, which was subducted in a southwestward direction (current coordinate). Our research thus highlights the presence of a previously unknown magmatic arc in this region.
Acknowledgments: I would like to express my sincere gratitude to my research supervisor, Dr. S. Turbold, and to the staff of the Institute of Geology, Mongolian Academy of Sciences, for their valuable guidance, support, and assistance throughout this research.

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We would like to express our sincere gratitude for the financial support received from Prof. Schulmann of the Czech Geological Survey and Prof. Lexa from Charles University for our analysis. We also extend our appreciation to Dr. Míková for her valuable assistance with zircon U-Pb dating at the Czech Geological Survey.

Geological structure of the "Erdenetiin Ovoo" copper-molybdenum group deposit

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This abstract summarizes the structural and geological setting of the Northwest, Central, Intermediate, and the Oyut, which forms discrete stocks constituting the Erdenetiin Ovoo group deposit. The mineralization throughout the group deposit is genetically and spatially associated with intrusive bodies of the Erdenet Porphyry Complex, predominantly granodiorite porphyry and quartz diorite porphyry. These porphyritic intrusions cut the granitoid rocks of the Selenge Complex and generated discrete hydrothermal alteration–mineralization centers, characterized by pervasive hydrothermal metasomatism. Across the deposits, quartz–sericite–pyrite phyllic alteration is ubiquitous, whereas the potassic alteration, together with subordinate argillic and propylitic alteration, defines a hydrothermal alteration zoning of porphyry deposits. The phyllic and potassic alteration zones are spatially closely associated with the main zones of Cu–Mo mineralization.

The mineralization is characterized predominantly by silicification accompanied by quartz–sulfide veins, veinlets, stockworks, and disseminated sulfides. In the Northwest, primary sulfide minerals, including chalcopyrite, bornite, pyrite, covellite, and molybdenite, predominate at the 1130 m of elevation. In contrast, the Central is characterized by the predominance of secondary copper sulfides and supergene oxide-zone ores in the near-surface parts above the 1355 m of elevation.

For the well-studied Northwest, the highest-grade mineralization is directly associated with the supergene enrichment zone (~150-200 m thick), where Cu grades increase by more than an order of magnitude, reaching up to 7.6 wt.% Cu. In the primary ore, Cu grades range from 0.4–0.5 wt.% at depths of up to 500 m below the surface and decrease to 0.2–0.3 wt.% at depths of 500–1000 m, while the average Mo grade is approximately 0.025 wt.%. For the Northwest and Central deposits combined, the estimated resource comprises 4.6 billion tons of ore grading 0.29 wt.% Cu, corresponding to 13.4 million tons Cu, and 0.014 wt.% Mo, corresponding to 642.5 thousand tons Mo. The Oyut, located at an elevation of approximately 1,408 m above sea level, has been investigated by drilling to depths of up to 930 m during the exploration conducted in 2023-2026. It is estimated a resource of approximately 404 million ton of ore grading 0.30 wt.% Cu, containing 1.2 million tons of Cu metal. In contrast, the Intermediate remains relatively poorly studied, and exploration program has not been conducted.

The Central is separated from the Northwest by the Central Fault, which trends northwest–southeast, and is distinguished from the Intermediate by a parallel fault. The porphyry body in the Intermediate is locally concealed and truncated by younger sedimentary rocks toward the southeast, and the zone is separated from the Oyut by the Khuuvur valley.

At the regional structural scale, the early stage was characterized by the development of extensional faults trending ENE, parallel to the suture zone of the Mongol–Okhotsk Ocean subduction system and interpreted as extensional structures associated with a back-arc rift basin. During the subsequent stage, the "Erdenet transverse zone" developed, comprising NW-trending extensional faults and dextral oblique-shear structures (R shears). The Erdenetiin Ovoo group deposit is spatially located within this structural domain. Finally, within the approximately 1–2 km wide and ~12 km long dextral strike-slip zone, which produced a prominent subvertical structural corridor, NNE-trending extensional-stage faults characterized by sinistral displacement (R' shears) developed. Collectively, these structural

systems formed extensional environments, thereby providing favorable conditions for the emplacement of porphyritic intrusions and the development of porphyry mineralization (Armelle et al., 2026, unpublished report).

The Northwest is characterized by intense silicification, a well-developed quartz–sulfide stockwork system, and a large supergene enrichment zone. Among the group deposits, it represents the most fully developed and highest-grade principal center of mineralization. In the Central, mineralization is closely associated with major tectonic faults, which exerted a dominant control on the shape, strike, and distribution of the ore bodies. The Intermediate represents a transitional domain and a continuation of the mineralization system from the Central. Although the intensity of mineralization is comparatively weaker, phyllic and argillic alteration are developed, together with hydrothermal alteration minerals such as Mg-rich chlorite and paragonite. In the Oyut, molybdenum grades are relatively low compare to Northwest, and mineralization is associated predominantly with sericitic–potassic alteration and chlorite–sericite alteration assemblages.

Tracking the early phase of closure of the Mongol-Okhotsk Ocean: Structural, Geochemical, and Zircon U-Pb Chronological Evidence from Northern Mongolia

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Keywords: Mongol-Okhotsk Ocean, Central Asian Orogenic Belt, volcanic rocks, subduction, zircon U-Pb geochronology

The Central Asian Orogenic Belt (CAOB) represents one of the largest accretionary orogens globally, yet the spatial-temporal evolution and eventual consumption of the Mongol-Okhotsk Ocean within this framework remain subjects of intense debate. This study investigates exceptionally well-preserved Middle Permian to LateTriassic volcanic sequences in northern Mongolia to better understand these tectonic processes in the region. The studied successions are stratigraphically diverse, consisting predominantly of intermediate to mafic volcanic rocks dominated by basalt and andesite interbedded with varying proportions of tuffaceous and volcaniclastic rocks. Structurally, these volcano-sedimentary sequences lack regional metamorphic overprints and exhibit no intensive internal deformation. Primary sequentially bedded volcanic rocks are remarkably preserved, exhibiting variable shallow-to-steep dip angles predominantly oriented toward the NNE or SSW, which is attributed to late, weak deformation without any associated metamorphic overprint. Whole-rock trace and rare earth element (REE) geochemical analyses reveal strong, highly consistent subduction-related chemical signatures across both sequences. The volcanic suites are characterized by marked enrichments in large-ion lithophile elements (LILEs, Rb, Ba, Th) and light rare earth elements (LREEs) relative to heavy rare earth elements (HREEs), coupled with pronounced negative anomalies in high field strength elements (HFSEs, Nb, Ta, and Ti). These diagnostic "subduction fingerprints" indicate that the magmatic suites were derived from a source heavily metasomatized by subduction-related fluids and melts. High-precision zircon U-Pb geochronological dating of these suites yields precise magmatic crystallization ages spanning the Middle Permian to Late Triassic (ca. 266–228 Ma). This age gap demonstrates that active-margin volcanism along this margin persisted or recurred over a prolonged duration of approximately 38 Myr. Notably, both dated samples contain inherited Proterozoic and lower-middle Paleozoic zircons, providing clear evidence for the recycling and reworking of ancient basement crust during magma generation. Conclusively, these combined structural, geochemical, and geochronological frameworks indicate that northern Mongolia was situated along an active convergent margin driven by the subduction of the Mongol-Okhotsk oceanic plate. The long-lived magmatism recorded between ca. 266 Ma and 228 Ma captures the earlier phase of the closure of the Mongol-Okhotsk Ocean. In synthesis, the preservation of these sequentially bedded primary volcanic rocks provides critical constraints on active margin dynamics, offering robust spatial-temporal parameters for the tectonic evolution, crustal recycling, and ultimate closure history of the Mongol-Okhotsk oceanic domain within the northern sector of the CAOB.

Acknowledgments
We gratefully acknowledge Prof. Ren Qiang for his valuable assistance with U–Pb geochronological dating and his generous support throughout the course of this study.

U-Pb and Hf isotopic analysis of Paleozoic sedimentary rocks from the Artsbogd Mountain range in southern Mongolia.

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Keywords: Paleozoic sedimentary rocks, Gobi-Altai Zone, Mongolian Altai Zone, Southern Mongolia

This study provides a comprehensive analysis of the source, metamorphism, deformation stages, and depositional age of both sedimentary and metamorphic rocks from the Zalaa Mountain in the Arts Bogd Mountain Range of Southern Mongolia. Field studies reveals three distinct geological structures in the Arts Bogd Range, extending from southwest to northeast. Primary strata (S0) are present in Devonian-Permian sedimentary rocks located in the southern and central parts of the area. In the northeastern part of the section, sedimentary rocks previously classified as Neoproterozoic by earlier workers have been metamorphosed up to greenschist facies (S_1). These rocks exhibit gentle folding and have experienced post-metamorphic deformation (D2), resulting in subvertical cleavage and a steep axial plane oriented in the SW-NE direction. The geochemical composition of the analyzed samples is primarily graywacke, derived from both felsic and mafic volcanic sources. These rocks show depletion of High Field Strength Elements (HFSE: Ta, Nb, Hf, Ti) and are geochemically consistent with formation in a subduction-related active continental margin setting. The southern section, previously classified as Permian, is now dated to the Lower Devonian (ca. 402 Ma). The central section is dated to the Lower Permian (ca. 277 Ma), while the northeastern section is dated to the Neoproterozoic, is now dated to the Upper Ordovician (ca. 447 Ma). The results demonstrates that the sedimentary rocks in the study area can be classified at a comparable level to the metasedimentary rocks of the Mongolian Altai Zone. These findings suggest that the Arts Bogd area may serve as an eastern extension of the Mongolian Altai Orogenic Belt.

REE+Y composition of different microfacies indicates preservation of highly variable paleoredox information in Cambrian phosphorites of central Asia

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Keywords: REE+Y, geochemistry, taphonomy

In marine sediments, spatial variations in oxygen create variations in the distribution of redox-sensitive ions, including many transition metals and Rare Earth Elements and Yttrium (REE+Y) (Haley et al., 2004; Deng et al., 2017). These variations can be significant over fine (submillimeter) spatial scales and may provide insight into the conditions for sedimentary processes such as phosphate mineralization (phosphogenesis) (Lumiste et al., 2019; Lumiste et al., 2021; Soares et al., 2024). However, redox conditions continue to evolve after deposition, altering the trace element chemistries of phosphatic sediments and cements (Sholkovitz et al., 1989; Haley et al., 2004; Reynard et al., 1999; Lumiste et al., 2019). Calcium-phosphate minerals precipitating from fluids readily incorporate redox-sensitive metals and REE+Y as they form, but it is unclear to what extent primary and earliest diagenetic processes control the distribution and textural associations of those elements compared to later diagenetic processes (Reynard et al., 1999; Lumiste et al., 2019; Soares et al., 2024). Here we report detailed petrography and REE+Y compositions of early Cambrian fossiliferous phosphorites from the Bayangol and Salaagol formations of the Zavkhan terrane in southwestern Mongolia. Petrographic observations strongly indicate organic matter-associated authigenic and early diagenetic phosphogenesis within fossil skeletons and restricted pore spaces rather than wholesale diagenetic replacement of a non-phosphatic primary phase. Spatial distributions of apatite and carbonate cements are highly variable across and within bioclasts, suggesting unique parageneses and non-uniform phosphatization processes. REE+Y compositions of texturally diverse apatite cements and sediments were measured using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), revealing broad preservation of depositional and early diagenetic signals but with texture- and outcrop-specific differences. La_N/Yb_N ratios in most samples are above seawater values, indicating early diagenetic adsorption as the primary mechanism of REE+Y uptake by phosphate minerals, and La_N/Sm_N ratios are consistently greater than values associated with late diagenetic uptake (Reynard et al., 1999). Strong middle REE (MREE) enrichment can therefore be explained by uptake from MREE-enriched porewaters during early diagenesis rather than preferential substitution of MREEs into apatite during recrystallization (Reynard et al., 1999; Lumiste et al., 2021). While MREE enrichment in porewaters results from dissolution of Fe-Mn oxyhydroxides in reducing conditions, true negative Ce anomalies in almost all samples suggest prolonged interaction with oxic seawater (Fig. 1), suggesting phosphogenesis occurred near the sediment water interface and, likely, across a relatively shallow redoxcline (Haley et al., 2004; Lumiste et al., 2021). Y/Ho values decrease with increasing Sm_N/Yb_N, indicating the progressive release of particulate-bound Ho and MREEs in anoxic porewaters (Haley et al., 2004; Lumiste et al., 2019).

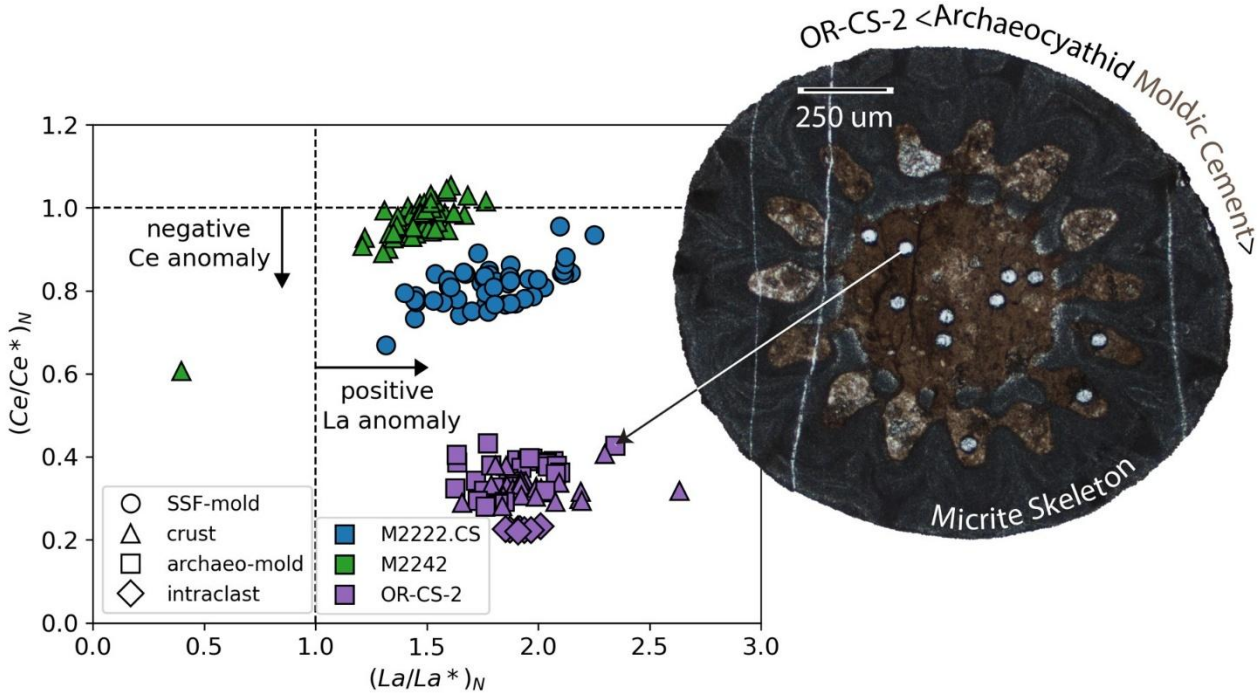


Figure 1. $(Ce/Ce^*)_N$ vs $(La/La^*)_N$ plot with photomicrograph showing example LA-ICP-MS analysis of moldic apatite cement within archaeocyathid skeletal cavity (specimen ID = OR-CS-2). Ce* is calculated as (Pr^2/Nd) and La* as (Pr^3/Nd^2) per Lawrence et al. (2006), with all values normalized to Post Archean Australian Shale. Plot is modified after Barrat et al. (2023) and Soares et al. (2024). M2222.CS, M2242, and OR-CS-2 are specimen IDs, each from a different locality within tens of meters of one other.

Further, REE+Y patterns are strongly controlled by locality, though different cement phases from the same locality can exhibit distinct REE patterns and abundances which may reflect their distinct parageneses (e.g., hardground cements versus moldic cements in bioclast cavities). Localities in close spatial proximity to each other (tens of meters-scale) show high variability, suggesting that differences in local depositional or early diagenetic conditions exerted the strongest control on REE+Y distribution rather than late diagenetic processes acting upon the Bayangol and Salaagol formations regionally.

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Formation of the pillow lava from the Bayankhongor ophiolite

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Keywords: Pillow lava, EMORB, OIB

The Neoproterozoic Bayankhongor Ophiolite in western Mongolia represents one of the largest oceanic rift basins in the Central Asian Orogenic Belt (CAOB), making it a critical locality for understanding early crustal growth and mantle dynamics. However, its tectonic evolution remains fiercely debated, with conflicting models supporting either subduction-unrelated or subduction-related settings. This study presents new field observations, petrological characteristics, whole-rock geochemical data, and Sm-Nd isotopic data from the Bayankhongor pillow lavas to clarify their geological structure, mantle source characteristics, and tectonic history. Field mapping confirms well-preserved, classic subaqueous volcanic architectures; the basaltic lavas exhibit typical pillow structures, prominent chilled margins, and distinct macro-textures, verifying rapid quenching in a marine setting. Petrologically, the lavas are predominantly composed of clinopyroxene and plagioclase, with amphibole occasionally present, exhibiting texturally diagnostic features typical of altered basaltic oceanic crust. Geochemically, the analyzed samples range from sub-alkaline to alkaline basalts with predominantly tholeiitic to transitional affinities. A single sample exhibits a baseline normal mid-ocean ridge basalt (N-MORB) signature, whereas the remaining suite is markedly enriched in light rare earth elements (LREEs), closely resembling enriched mid-ocean ridge basalt (E-MORB) and ocean island basalt (OIB). Elevated concentrations of high-field strength elements (Th, Ta, Nb, Zr, Hf, and Ti) further confirm a primary mantle-derived origin. Tectonic discrimination diagrams illustrate a continuum between E-MORB and within-plate basalt, indicative of an active, plume-influenced mid-ocean ridge. Based on LREE fractionation, the samples are categorized into three distinct suites (low N-MORB, high E-MORB, and OIB), interpreted as the product of advanced partial melting and the mixing of MORB and OIB mantle reservoirs. Sm-Nd isotopic data yield a single-stage model age (T_DM1^Nd) of 727 Ma, representing the fractional crystallization of a basaltic magma derived from an initially depleted mantle. Whole-rock initial Nd values (e_Nd(600) = +8.1 to +2.4) firmly reinforce a mid-ocean ridge origin. While our field, petrological, and geochemical data strongly support a subduction-unrelated oceanic rift basin during the initial magmatic accretion phase, we propose an integrated, polyphase tectonic model. This framework reconciles our rifting data with recent subduction-related records by framing them as distinct, sequential stages of a single Wilson Cycle, tracking the Bayankhongor basin from Neoproterozoic plume-influenced spreading to its subsequent convergent closure.

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Stratigraphic Framework and Depositional Age of Late Paleozoic–Mesozoic Sequences in Khüren Khanyn Khets, Noyon Basin

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Keywords: Noyon Basin; Noyonsum Formation; U–Pb detrital zircon geochronology

Continental Permian–Triassic sequences are widely distributed across the eastern Gobi–Tien Shan belt (Noyon and Tost ranges). These sequences fill the Noyon Basin, situated more than 200 km southwest of Dalanzadgad, Ömnögovi. The basin is a large, ~200 km long orogenic synclinal structure built around a central uplift and comprising three limbs, which are northern, southern, and eastern. Its core consists mainly of Late Carboniferous intermediate effusive-pyroclastic rocks. The central limb is built of Late Permian–Triassic molasse, whereas the outer limb comprises Jurassic sandstone (Amantov et al., 1970; Mossakovsky & Tumurtogoo, 1976). From base to top, the succession comprises the Tost (C_{1-2}ts), Togoot Khar (P_1th), Deliinshand Khudag (P_2ds), Baysakh (T_1ba), Noyonsum (T_{2-3}ns), and Sainsar (J_{1-2}ss) formations, consisting predominantly of volcano-sedimentary rocks and conglomerate-sandstone-siltstone sequences, and is unconformably overlain by Quaternary sediments. This study focuses on the Noyonsum Formation at Khüren Khanyn Khets, at the heart of the Noyon syncline, a flora-bearing sedimentary succession that provides important constraints on the age and palaeoenvironment of the basin. An Early Permian flora was first documented by Efremov and Novozhilov (1952), with further collections by Amantov, Volchok, Luvsandanzan, Suetenko, and Borzakovsky. Durante (1971, 1976) divided the succession by age, assigning the lower, red-bed siltstone-sandstone unit to the Middle–Late Permian Deliinshand Khudag Formation and the upper, flora-bearing sandstone-conglomerate-siltstone unit to the Triassic Noyonsum Formation. Mossakovsky and Tumurtogoo (1976) subdivided the Noyonsum Formation into four packages and twelve cyclic units. Recent paleobotanical work (Dorjsuren & Luvsantseden, 2024) recovered *Cladophlebis* sp., *Neocalamites* sp. and *Pityophyllum* sp. from packages 2 and 4, supporting a Middle–Late Triassic age, but the formation lacked an independent radiometric age control until now. New field mapping at Khüren Khanyn Khets (Figure 1) documents the contact between the Baysakh (T_1ba) and Noyonsum (T_{2-3}ns) formations and a nine-unit composite stratigraphic column dominated by cyclic sandstone and conglomerate with mudstone/siltstone interbeds and multiple plant-fossil horizons (Figure 2). Thinsection analysis shows that the sandstone from the Noyonsum Formation (MK22–2626) is a moderately to well sorted lithic arenite (85–90% clasts, 10–15% sericite-carbonate cement: quartz 15–20%, plagioclase 10–15%, K-feldspar ~5%, felsic effusive clasts ~30%, andesite 20–25%, microschist 5–10%, microquartzite ~5%). Basalt from the Deliinshand Khudag Formation (MK22–2629) is hyalopilitic and amygdaloidal (plagioclase 75%, olivine 10–15% partly altered to iddingsite, volcanic glass 10–15%). Plant macrofossils collected from the Noyonsum Formation (MK22–2632/1, MK22–2631/1) include stem fragments assigned to *Neocalamites* sp. (Calamitales), consistent with earlier finds of *Equisetites*, *Cladophlebis*, *Pelourdea*, *Sphenobaiera* and

Pityophyllum spp. (Dobruskina) and casarthrid crustaceans (Badamgarav et al., 1984), together indicating a Middle–Late Triassic age for the plant-bearing horizons.

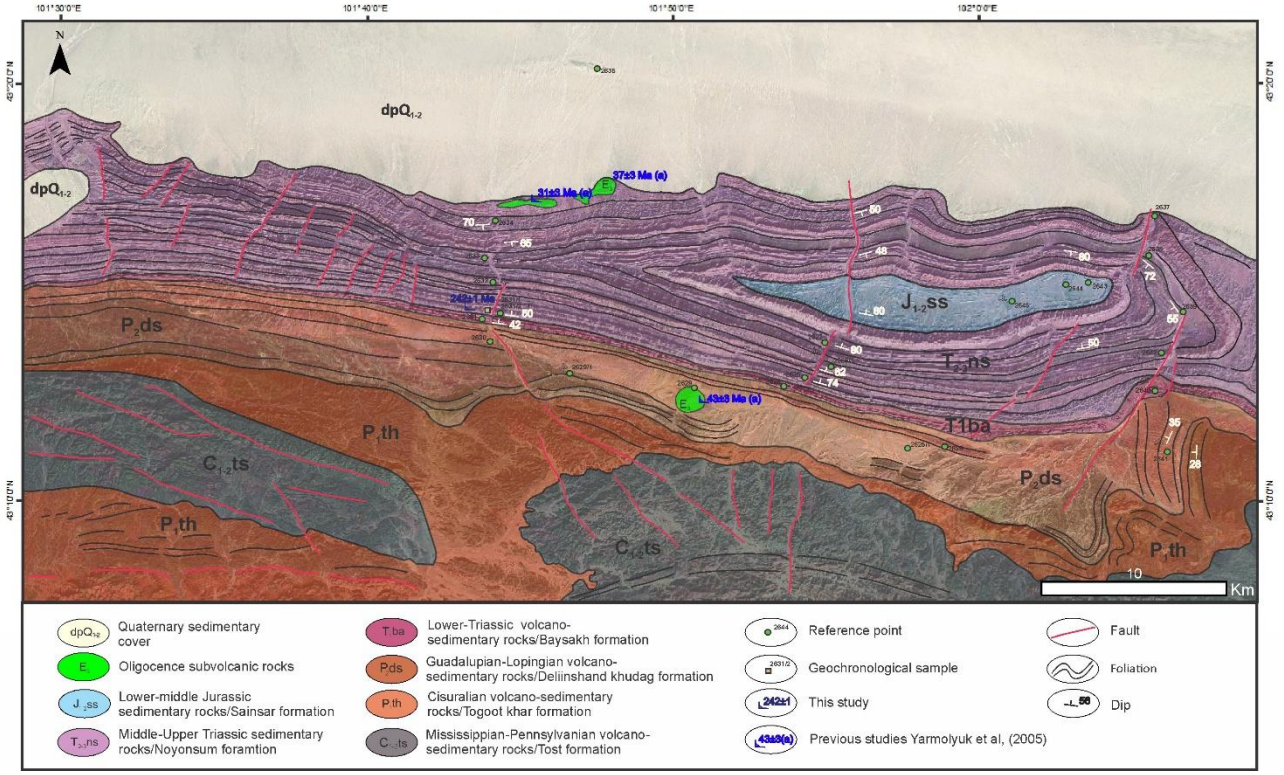


Figure 1. Geological map of the Khüren Khanyn Khets area, Noyon Basin, showing the distribution of Carboniferous–Jurassic formations, faults, dip/foliation measurements, and geochronological sample localities.

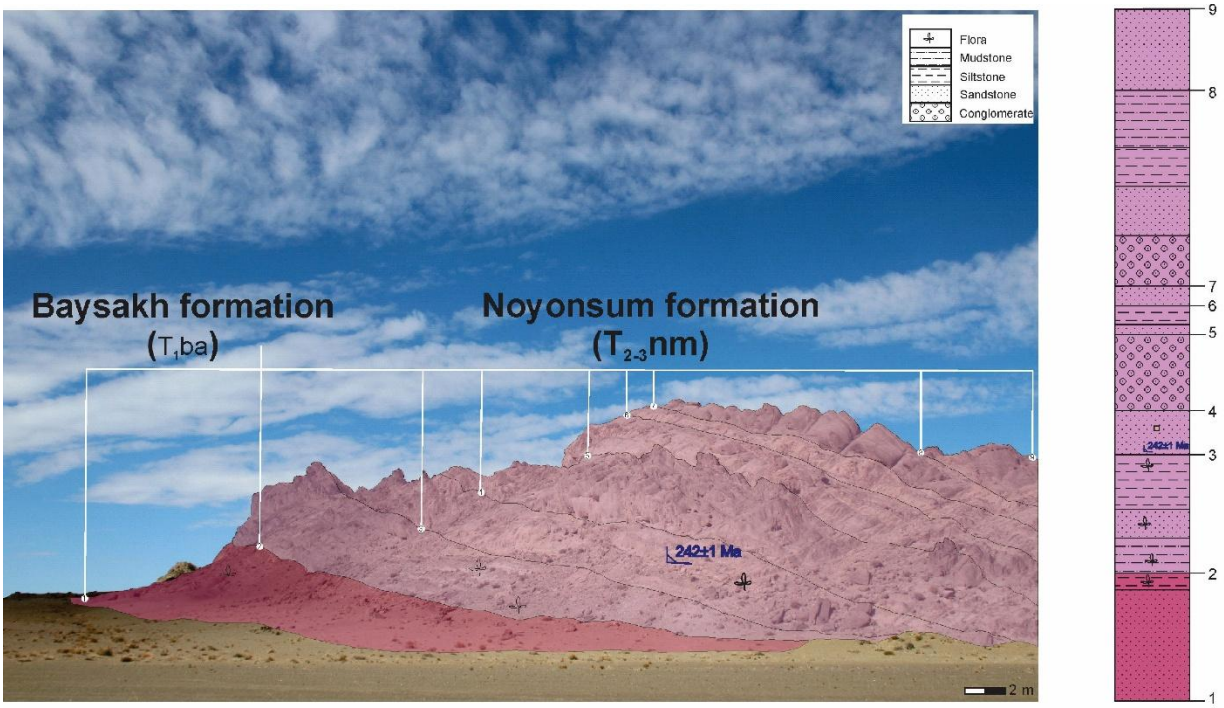


Figure 2. Field photograph and composite stratigraphic column of the Baysakh (T_1ba) and Noyonsum (T_{2-3}ns) formations, showing lithology, plant-fossil horizons, and the position of U–Pb sample MK22–2631/2.

To obtain an independent radiometric age constraint, we conducted U–Pb detrital-zircon geochronology (Figure 3) on sample MK22–2631/2, a medium-to-coarse-grained greenish-brown sandstone from the lower Noyonsum Formation (101.7339°E, 43.2374°N). Of more than 100 zircons analyzed, 83 grains with ≥92% concordance and Th/U ratios of 0.66–1.44 (consistent with a magmatic origin) were used to constrain sediment provenance and the maximum depositional age. Ages range from 1953 ± 18 Ma to 237 ± 2 Ma and define five populations: 1849–1983 Ma (N = 4, Paleoproterozoic), 691–963 Ma (N = 8, Neoproterozoic), 431–537 Ma (N = 19, Cambrian–Silurian), 251–412 Ma (N = 35, weighted mean 299.5 Ma, Devonian–Permian) and 237–246 Ma (N = 17, weighted mean 242.14 −0.95/+1.51 Ma, MSWD = 2.2). The youngest zircon population constrains the maximum depositional age of the Noyonsum Formation to 242.1 ± 0.95 Ma (Middle Triassic), providing the first radiometric age for this unit and independent confirmation of the Middle–Late Triassic age previously inferred from plant macrofossils.

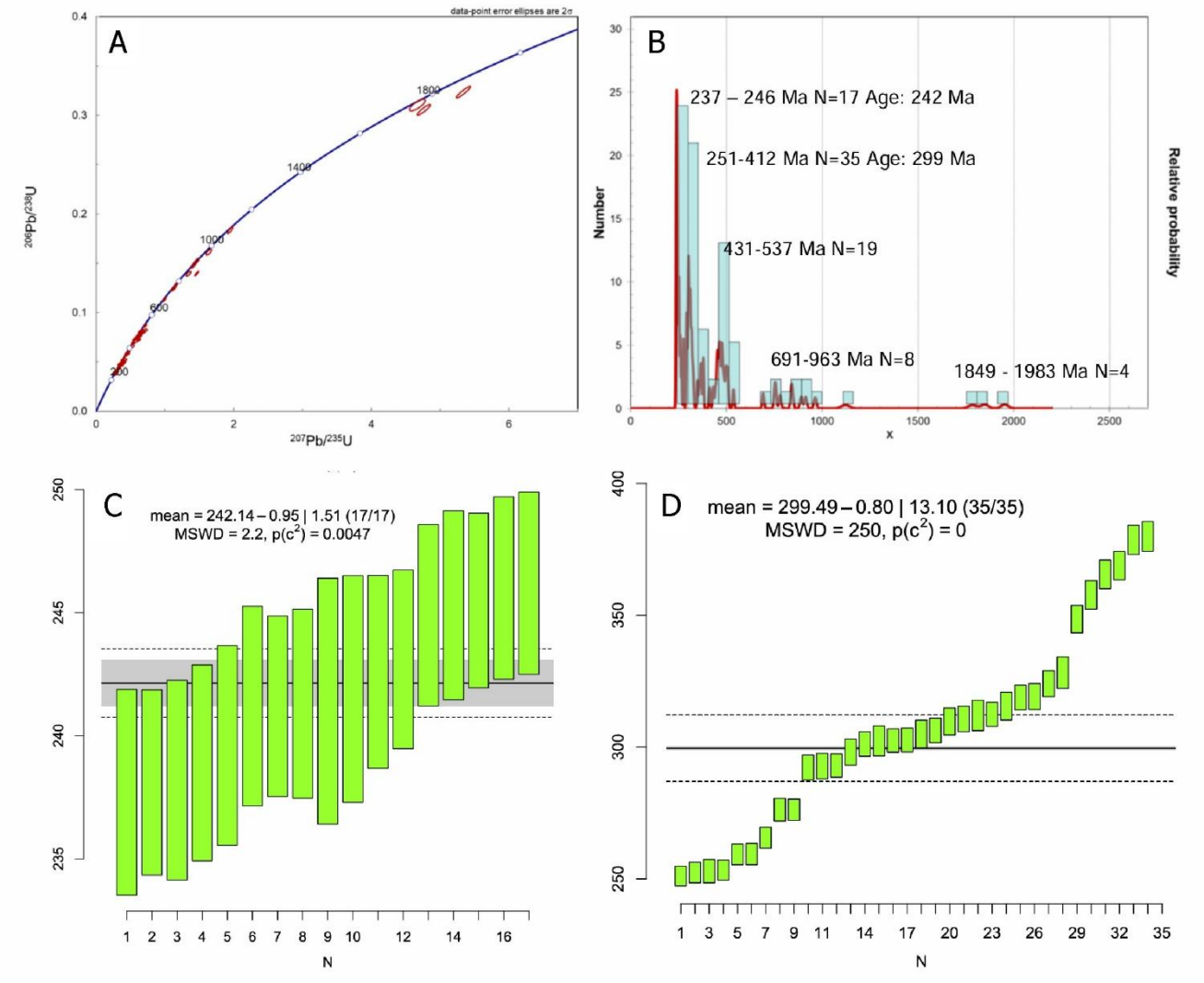


Figure 3. Detrital-zircon U–Pb geochronology, sample MK22–2631/2. (A) Concordia diagram. (B) Relative-probability age spectrum. (C) Weighted mean of the youngest population, 242.14 −0.95/+1.51 Ma (n = 17/17, MSWD = 2.2), the maximum depositional age. (D) Weighted mean of the 251–412 Ma population, 299.49 Ma (n = 35/35).

In conclusion, new U–Pb detrital-zircon data establish a maximum depositional age of 242.1 ± 0.95 Ma (Middle Triassic) for the Noyonsum Formation at Khüren Khanyn Khets. This age is consistent with the Middle–Late Triassic plant macrofossil assemblages. Detrital-zircon provenance data further indicate that the Noyonsum sediments were derived from regional basement rocks and Gobi–Tien Shan rift-related magmatic sources, supporting to refine the Late Paleozoic–Mesozoic stratigraphic framework of the Noyon Basin. The well-exposed and fossil-rich sections at Khüren Khanyn Khets additionally highlight the site's importance for natural-heritage conservation and its potential for geotourism.

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Geochemistry and geochronology of granitoid rocks from the Egiindavaa Complex in Khangai region, central Mongolia

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The Egiindavaa Complex is a large composite granitoid body exposed in the Khangai region of central Mongolia, within the western segment of the Mongol–Okhotsk Orogenic Belt. Despite its regional importance, the timing of emplacement, magmatic evolution, petrogenesis, and tectonic setting of the complex remain insufficiently constrained. This study integrates field observations, petrographic characteristics, whole-rock major- and trace-element geochemistry, and zircon U–Pb geochronology to investigate the origin and tectono-magmatic evolution of the Egiindavaa Complex.

The complex consists of three intrusive phases: Phase I, represented mainly by granodiorite, diorite, and quartz diorite; Phase II, composed predominantly of biotite and biotite–hornblende granite; and Phase III, represented by leucogranite and associated late felsic intrusions. Petrographic observations show that the rocks are dominated by quartz, plagioclase, and K-feldspar, with variable amounts of biotite and amphibole and accessory zircon, apatite, and sphene. The granitoids are silica-rich (SiO_2 = 59.44–74.24 wt.%), high-K calc-alkaline to locally shoshonitic, and weakly to moderately peraluminous (A/CNK > 1.05). Their primitive mantle-normalized trace-element patterns are characterized by enrichment in large-ion lithophile elements (LILE), particularly Cs, Th, U, and Li, and pronounced negative anomalies in Nb, Ta, P, and Ti. Chondrite-normalized REE patterns show enrichment of light rare earth elements (LREE) relative to heavy rare earth elements (HREE), relatively flat HREE patterns, and weak negative Eu anomalies, indicating progressive magmatic differentiation with minor to moderate feldspar fractionation.

Zircon U–Pb geochronology yields weighted mean $^{206}Pb/^{238}U$ ages of 234 ± 2 Ma for biotite granite from the southern part of the complex and 232 ± 1 Ma for gneissose granite from the northern part. These ages demonstrate that the Egiindavaa Complex was emplaced during the Late Triassic at ca. 234–232 Ma. The combined petrographic, geochemical, and geochronological data indicate that the complex is dominated by I-type granitoids and records an evolved calc-alkaline magmatic system. The strong LILE enrichment and HFSE depletion indicate a significant subduction-related geochemical signature, whereas tectonic discrimination diagrams also suggest characteristics transitional between volcanic-arc, collisional, and post-collisional settings. We therefore interpret the Egiindavaa Complex as recording late-stage convergent to post-collisional magmatism associated with the tectono-magmatic evolution and final stages of closure of the Mongol–Okhotsk Ocean. These results provide new constraints on Late Triassic granitoid magmatism and contribute to understanding the crustal evolution of central Mongolia.

Multistage metamorphic records from the Zunaigol Formation: Preliminary Data

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The study area is located southwest of Murun city in northern Mongolia and is a component of the northern limb of the large-scale Mongol-Orocline structure. A comprehensive understanding of the tectonic settings is essential for effectively analyzing the metamorphic and deformation processes within this region. The Zunaigol formation is composed of mostly the high-grade metamorphic rocks, including marble, orthogneiss, augen gneiss, paragneiss, garnetiferous amphibolite, and migmatitic gneisses. These rocks have undergone multiple phases of deformation (D1, D2, D3), resulting in a structural framework characterized by SE steeply dipping cleavages (S3), which have reworked the older foliations (S1, S2). While the structural relationships between the older and later deformations were not entirely evident at the field sites examined, distinct metamorphic fabrics have been observed at the microstructural scale. The S1 foliation includes mica schist, garnetiferous metapellite, and schist that contains the relicts of likely kyanite, whereas S2 is characterized by high-temperature fabrics comprising high-grade assemblages such as garnet-sillimanite gneiss and garnetiferous amphibolite. S3 is notably distinguished by its axial planar cleavage. The presence of garnets in gneisses serves as an indicator of prograde metamorphism, as evidenced by the formation of sillimanite rims surrounding the garnets. In certain instances, sillimanite can nearly entirely replace the garnets. This mineral is observed both within high-grade mineral assemblages as a groundmass and as a rim encasing either the garnets or the relicts of aluminum silicate minerals such as kyanite or andalusite. Additionally, the amphibolite exhibits garnets with plagioclase rims, which suggest retrograde metamorphism. The process in question appears to be associated with isothermal decompression that takes place during the exhumation of deeper crustal rocks. Evidence obtained from the analysis of these metamorphic rocks indicates that they were initially subjected to MP-MT regional metamorphism, followed by influences from HT events, likely occurring in the deeper crust. Subsequently, these rocks experienced cooling during the exhumation process as a result of decompression. The previously metamorphosed rocks have undergone further modification due to post-metamorphic deformation (S3). This process has resulted in the development of vertical cleavages that can be observed within the outcrop. In conclusion, this work provides preliminary data and outlines a roadmap for future research, which will include P-T calculations. This research aims to advance our understanding within the frameworks of deformation and tectonic analysis, as well as examining the associated regional geological implications.

REFERENCES

Badarch, G., Cunningham, W.D. & Windley, B.F. (2002) A new terrane subdivision for Mongolia: implications for the Phanerozoic crustal growth of Central Asia *J. Asian Earth Sci*. **21**: 87–110.

Bold, U., Crowley, J.L., Smith, E.F. *et al.* (2016) Neoproterozoic to early Paleozoic tectonic evolution of the Zavkhan terrane of Mongolia: Implications for continental growth in the Central Asian orogenic belt Open Access *Lithosphere*, **8**: 729–750

Buriánek, D., Schulmann, K., Hrdličková, K. *et al.* (2017) Geochemical and geochronological constraints on distinct Early-Neoproterozoic and Cambrian accretionary events along southern margin of the Baydrag Continent in western Mongolia *Gondwana Res*. **47**: 200–227.

Collett, S., Soejono, I., Peřestý, V. *et al.* (2024) Mongolian micro-continental blocks in Columbia/Nuna: Zircon U–Pb–Hf isotopic evidence for long-lasting Mongolia–Western Siberia connection. *Terra Nova* **36**: 171–181

Donskaya, T.V., Gladkochub, D.P., Fedorovsky, V.S. *et al.* (2017) Pre-collisional (> 0.5 Ga) complexes of the Olkhon terrane (southern Siberia) as an echo of events in the Central Asian Orogenic Belt. *Gondwana Res.* **42**: 243–263.

Furnes, H. & Safonova, I. (2019) Ophiolites of the Central Asian Orogenic Belt: Geochemical and petrological characterization and tectonic settings. *Geosci. Front*. **10**: 1255–1284

Ge, R., Zhu, W. & Wilde, S.A. (2016) Mid-Neoproterozoic (ca. 830–800 Ma) metamorphic P-T paths link Tarim to the circum-Rodinia subduction-accretion system *Tectonics* **35**: 1465–1488

Gladkochub, D.P., Donskaya, T.V., Wingate, M.T.D. *et al.* (2008) Petrology, geochronology, and tectonic implications of c. 500 Ma metamorphic and igneous rocks along the northern margin of the Central Asian Orogen (Olkhon terrane, Lake Baikal, Siberia) *J. Geol. Soc.* **165**: 235–246

Gladkochub, D.P., Motova, Z.L., Donskaya, T.V. *et al.* (2022) Cambrian/Ordovician boundary as a milestone in the sedimentation history of the southern Siberian craton: Evidence from U-Pb dating of detrital zircons *J. Asian Earth Sci*. **8**: 100107

Janoušek, V., Jiang, Y., Buriánek, D. *et al.* (2018) Cambrian–Ordovician magmatism of the Ikh-Mongol Arc System exemplified by the Khantaishir Magmatic Complex (Lake Zone, south–central Mongolia) *Gondwana Res*. **54**: 122–149

Jian, P., Kröner, A., Windley, B.F. *et al.* (2010) Zircon ages of the Bayankhongor ophiolite mélange and associated rocks: time constraints on Neoproterozoic to Cambrian accretionary and collisional orogenesis in Central Mongolia *Precambr. Res*. **177**: 162–180

Jian, P., Kröner, A., Jahn, B.M. *et al.* (2014) Zircon dating of Neoproterozoic and Cambrian ophiolites in West Mongolia and implications for the timing of orogenic processes in the central part of the Central Asian Orogenic Belt. *Earth-Sci. Rev*. **133**: 62–93

Kuzmichev (2015) Kuzmichev A.B. Neoproterozoic accretion of the Tuva-Mongolian massif, one of the Precambrian terranes in the Central Asian Orogenic Belt. In: A. Kroner (ed.) Composition and evolution

of Central Asian Orogenic Belt: Geology, Evolution,Tectonics, and Models. *The Central Asian Orogenic Belt, Borntraeger*, pp. 66–92

Li, Z., Jiang,Y., Collett, S. *et al.* (2023) Metamorphic and chronological constraints on the early Paleozoic tectono-thermal evolution of the OlkhonTerrane, southern Siberia *J. Metamorph. Geol.* **41**: 525–556

Motova, Z.L., Donskaya,T.V., Gladkochub, D.P. & Khubanov, V.B. (2024) U-Pb ages of detrital zircons and composition of clastic sedimentary rocks from the southern periphery of the Siberian craton: Implications for the earliest Cambrian evolution of southern Siberia. *J. Asian Earth Sci.* **264**: 106048

Peřestý, V., Soejono, I., Schulmann, K. *et al.* (2025) Late Cambrian Syn-IntrusiveThickening of the Ikh Mongol Arc Domains in the Mongolian Collage. *Tectonics* **44**, e2024TC008437

Safonova, I., Seltmann, R., Kröner, A. *et al.* (2011) A new concept of continental construction in the Central Asian Orogenic Belt. *Episodes* **34**: 186–196

Skuzovatov, S., Wang, K.L., Dril, S. *et al.* (2019a) Geochemistry, zircon U-Pb and Lu-Hf systematics of high-grade metasedimentary sequences from the South Muya block (northeastern Central Asian Orogenic Belt): reconnaissance of polymetamorphism and accretion of Neoproterozoic exotic blocks in southern Siberia. *Precambr. Res.* **321**: 34–53

Skuzovatov, S., Shatsky, V. & Wang, K.L. (2019b) Continental subduction during arc-microcontinent collision in the southern Siberian craton: Constraints on protoliths and metamorphic evolution of the North Muya complex eclogites (Eastern Siberia). *Lithos* **342**: 76–96

Soejono, I., Janoušek, V., Peřestý, V. *et al.* (2023) From Rodinian passive margin to *peri*-Siberian continental arc: Evidence from the multiphase Neoproterozoic–early Paleozoic magmatic record of the Zavkhan Block in the Mongolian Collage. *Gondwana Res.* **121**: 344–367

Soejono, I., Collett, S., Schulmann, K. *et al.* (2025) Neoproterozoic paleogeography and displacement of the Mongolian blocks constrained by detrital zircon ages and Hf isotopic systematics (Zavkhan Block, W Mongolia). *Precambr. Res.* **417**: 107657

Štípská, P., Schulmann, K., Lehmann, J. *et al.* (2010) Early Cambrian eclogites in SW Mongolia: evidence that the Palaeo-Asian Ocean suture extends further east than expected. *J. Metamorph. Geol.* **28**: 915–933

Štípská, P., Peřestý, V., Soejono, I. *et al.* (2023) Anticlockwise metamorphic paths at ca. 890–790 Ma from the NE Baidrag block, Mongolia, indicate back-arc compression at the Rodinia periphery. *Geosci. Front.* **14**: 101520

Štípská, P., Schulmann, K., Soejono, I. *et al.* (2024) Supra-subduction thickening of a continental back-arc: Ediacaran–early Cambrian (Baikalian) metamorphism in the NE Baidrag block (Mongolian Collage). *Gondwana Res.* **135**: 234–265

Sukhbaatar,T., Schulmann, K., Janoušek, V. *et al.* (2024) Magmatic and sedimentological arguments for an Ediacaran active margin in the Bayankhongor Zone in western Mongolia, Central Asian Orogenic Belt. *Gondwana Res.* **134**: 385–409

Wilhem, C., Windley, B.F. & Stampfli, G.M. (2012)The Altaids of Central Asia: A tectonic and evolutionary innovative review. *Earth-Sci. Rev.* **113**: 303–341

Xiao, W., Windley, B.F., Sun, S. *et al.* (2015) A Tale of Amalgamation of Three Permo-Triassic Collage Systems in Central Asia: Oroclines, Sutures, and Terminal Accretion. *Annu. Rev. Earth Planet. Sci.* **43**: 477–507

Zhu, M., Zhang, F., Smit, M.A. *et al.* (2023a) Discovery of a >1,000 km Cambrian Eclogite-Bearing High-Pressure Metamorphic Belt in the Central Asian Orogenic Belt: Implications for the Final Closure of the Pan-Rodinian Ocean. *J. Geophys. Res. Solid Earth* **128**: e2022JB025388

Zhu, M., Pastor-Galán, D., Smit, M.A. *et al.* (2024b) Ophiolites in the Central Asian Orogenic Belt record Cambrian subduction initiation processes. *Comm. Earth Environ.* **5**: 753

Chugaev, A.V., Budyak, A.E., Larionova, Y.O., Chernyshev, I.V., Travin, A.V., Tarasova, Y.I., Gareev, B.I., Batalin, G.A., Rassokhina, I.V., Oleinikova, T.I. 2022. ^{40}Ar-^{39}Ar and Rb-Sr age constraints on the formation of Sukhoi-Log-style orogenic gold deposits of the Bodaibo District (Northern Transbaikalia, Russia). *Ore Geology Reviews*, 144, 104855. https://doi.org/10.1016/j.oregeorev.2022.104855

Demonterova, E.I., Ivanov, A.V., Savelyeva, V.B. 2016. Mafic, Ultramafic and Carbonatitic Dykes in the Southern Siberian Cratonwith Age of ca 1 Ga: Remnants of a New Large Igneous Province? In: Acta Geologica Sinica (English Edition). Special Issue: The Seventh International Dyke Conference: Dyke Swarms: Keys to Paleogeographic Reconstruction IDC7, 18–20 August, Beijing, 90 (S1), 9. https://doi.org/10.1111/1755-6724.12851

Ernst, R.E., Gladkochub, D.P., Söderlund, U., Donskaya, T.V., Pisarevsky, S.A., Mazukabzov, A.M., El Bilali, H. 2023. Identification of the ca. 720 Ma Irkutsk LIP and its plume centre in southern Siberia: The initiation of Laurentia-Siberia separation. *Precambr. Res.,* 394, 107111. https://doi.org/10.1016/j.precamres.2023.107111

Ernst, R.E., Hamilton, M.A., Söderlund, U., Hanes, J.A., Gladkochub, D.P., Okrugin, A.V., Kolotilina, T., Mekhonoshin, A.S., Bleeker, W., LeCheminant, A.N., Buchan, K.L., Chamberlain, K.R., Didenko, A.N. 2016. Long-lived connection between southern Siberia and northern Laurentia in the Proterozoic. *Nature Geosciences*, 9 (6), 464–469. https://doi.org/10.1038/ngeo2700

Gladkochub, D.P., Donskaya, T.V., Pisarevsky, S.A., Kotov, A.B., Salnikova, E.B., Mekhonoshin, A.S., Sklyarov, E.V., Demonterova, E.I., Mazukabzov, A.M., Stepanova, A.V., Konstantinov, K.M. 2023. Mesoproterozoic (ca. 1.26 Ga) Srednecheremshansk mafic–ultramafic intrusion in the southern Siberia: Signature of the Mackenzie event in Siberia. *Precambr. Res.,* 390, 107038. https://doi.org/10.1016/j.precamres.2023.107038

Gladkochub, D.P., Donskaya, T.V., Stanevich, A.M., Pisarevsky, S.A., Zhang, S., Motova, Z.L., Mazukabzov, A.M., Li, H. 2019. U-Pb detrital zircon geochronology and provenance of Neoproterozoic sedimentary rocks in southern Siberia: New insights into breakup of Rodinia and opening of Paleo-Asian Ocean. *Gondwana Res.*, 65, 1–16. https://doi.org/10.1016/j.gr.2018.07.007

Gladkochub, D.P., Pisarevsky, S.A., Donskaya, T.V., Ernst, R.E., Wingate, M.T.D., Söderlund, U., Mazukabzov, A.M., Sklyarov, E.V., Hamilton, M.A., Hanes, J.A. 2010. Proterozoic mafic magmatism in Siberian craton: An overview and implications for paleocontinental reconstruction. *Precambr. Res.*, 183, 660–668. https://doi.org/10.1016/j.precamres.2010.02.023

Gladkochub, D.P., Donskaya, T.V., Motova, Z.L., Ivanov, A.V., Reshetov, E.V., Bortnikov, N.S. 2026. Ediacaran diamond-bearing sedimentary rocks from the southern Siberian Craton, Russia: Compositions

and U-Pb age of detrital zircons. *Gondwana Res.*, 157, 182–199. https://doi.org/10.1016/j.gr.2026.04.015

Li, Z.-X., Liu,Y., Ernst, R. 2023. A dynamic 2000–540 Ma Earth history: From cratonic amalgamation to the age of supercontinent cycle. *Earth-Science Reviews*, 238, 104336. https://doi.org/10.1016/j.earscirev.2023.104336

Meffre, S., Large, R.R., Scott, R., Woodhead, J., Chang, Z., Gilbert, S.E., Danyushevsky, L.V., Maslennikov, V., Hergt, J.M. 2008. Age and pyrite Pb-isotopic composition of the giant Sukhoi Log sediment-hosted gold deposit, Russia. *Geochim. Cosmochim. Acta*, 72, 2377–2391. https://doi.org/10.1016/j.gca.2008.03.005

Pisarevsky, S.A., Gladkochub, D.P., Donskaya, T.V. 2021. Precambrian paleogeography of Siberia. In: Pesonen L.J., Salminen J., Elming S.-Å., Evans D.A.D., Veikkolainen T. (Eds.), Ancient Supercontinents and the Paleogeography of the Earth. Amsterdam, Elsevier, Chapter 8, pp. 263–275. https://doi.org/10.1016/B978-0-12-818533-9.00012-6

Powerman, V., Shatsillo, A., Chumakov, N., Kapitonov, I., Hourigan, J. 2015. Interaction between the Central Asian Orogenic Belt (CAOB) and the Siberian craton as recorded by detrital zircon suites from Transbaikalia. *Precambr. Res.*, 267, 39–71. https://doi.org/10.1016/j.precamres.2015.05.015

Prokopyev, I.R., Doroshkevich, A.G., Varchenko, M.D., Semenova, D.V., Izbrodin, I.A., Kruk, M.N. 2024. Mineralogy and Zircon Age of Carbonatites of the Srednyaya Zima Complex (Eastern Sayan). *Geodynamics & Tectonophysics*, 15 (2), 0749. https://doi.org/10.5800/GT-2024-15-2-0749

Savelyeva, V.B., Demonterova, E.I., Danilova, Yu.V., Bazarova, E.P., Ivanov, A.V., Kamenetsky, V.S. 2016. New Carbonatite Complex in the Western Baikal Area, Southern Siberian Craton: Mineralogy, Age, Geochemistry, and Petrogenesis. *Petrology*, 24 (3), 292–324. https://doi.org/10.1134/S0869591116030061

Savelyeva, V.B., Danilova, Y.V., Letnikov, F.A., Demonterova, E.I., Yudin, D.S., Bazarova, E.P., Danilov, B.S., Sharygin, I.S., 2022. Age and melt sources of ultramafic dykes and rocks of the Bolshetagninskii alkaline carbonatite massif (Urik-Iya graben, SW margin of the Siberian Craton). *Doklady Earth Sci.*, 505, 452–458. https://doi.org/10.1134/S1028334X22070169

Stifeeva, M.V., Salnikova, E.B., Savelyeva, V.B., Kotov, A.B., Danilova, Yu.V., Bazarova, E.P., Danilov, B.S. 2023.Timing of carbonatite ultramafic complexes of the Eastern Sayan alkaline province, Siberia: U–Pb (ID–TIMS) Geochronology of Ca–Fe garnets. *Minerals*, 13 (8), 1086. https://doi.org/10.3390/min13081086

Yarmolyuk, V.V., Kovalenko, V.I., Sal'nikova, E.B., Nikiforov, A.V., Kotov, A.B., Vladykin, N.V. 2005. Late Riphean rifting and breakup of Laurasia: Data on geochronological studies of ultramafic alkaline complexes in the southern framing of the Siberian Craton. *Doklady Earth Sci.*, 404, 7, 1031–1036.

Alexeiev, D.V., Kröner, A., Hegner, E.; et al. Middle to Late Ordovician arc system in the Kyrgyz Middle Tianshan: From arc-continent collision to subsequent evolution of a Palaeozoic continental margin. Gondwana Res. 2016, 39, 261–291.

Clift, P.D., Vannucchi, P., 2004. Controls on tectonic accretion versus erosion in subduction zones: Implications for the origin and recycling of the continental crust. Rev. Geophys., 42, RG2001.

Safonova, I., Perfilova, A., 2023. Survived and disappeared intra-oceanic arcs of the Paleo-Asian Ocean: evidence from Kazakhstan. Natl Sci. Rev. 10 (2), nwac215.

Safonova, I., Seltmann, R., Kröner, A., Gladkochub, D., Schulmann, K., Xiao, W., Komiya, T., Sun, M., 2011. A new concept of continental construction in the Central Asian Orogenic Belt (compared to actualistic

examples from the Western Pacific). Episodes 34, 186–194.

Safonova, I., Savinskiy, I., Perfilova, A., et al., 2024. A new tectonic model for the Itmurundy Zone, Central Kazakhstan: linking ocean plate stratigraphy, timing of accretion and subduction polarity. Geosci. Front. 15, 101814.

Safonova, I., Gurova, A., Perfilova, A., et al., 2025. Magmatic complexes of the Tekturmas Fold-and-Thrust Belt, Central Kazakhstan: An overview and new implications for the early Paleozoic evolution of the Paleo-Asian Ocean. Earth Sci. Rev. 265, 105–120.

Savinskiy, I., Safonova, I., Perfilova, A., Kotler, P., Sato, T., Maruyama, S., 2021. A story of Devonian Ocean plate stratigraphy hosted by the Ulaanbaatar accretionary complex, northern Mongolia: implications from geological, structural and U–Pb detrital zircon data. Int. J. Earth Sci. 111, 2469-2492.

Scholl, D., von Huene, R., 2007. Crustal recycling at modern subduction zones applied to the past. Issues of growth and preservation of continental basement crust, mantle geochemistry, and supercontinent reconstruction. In: Hatcher, R.D., Jr., Carlson, M.P., McBride, J.H., Martínez Catalán, J.R. (Eds.), 4-D framework of continental crust. Geol. Soc. Am. Memoir 200, 9–32.

Vanucchi, P., Morgan, J.P., Balestrieri, M.L., 2016. Subduction erosion, and the de-construction of continental crust: The Central America case and its global implications. Gondwana Res. 40, 184-198.

von Huene, R., Ranero, C.R., 2003. Subduction erosion and basal friction along the sediment-starved convergent margin off Antofagasta, Chile. J. Geophys. Res. 108 (B2), 2079.

Dijkstra, A., Buchan, C., Dijkstra, A., Brouwer, F., Cunningham, W., Badarch, G., Mason, P. 2006. Late Neoproterozoic proto-arc ocean crust in the Dariv Range, Western Mongolia: A supra-subduction zone end-member ophiolite. *J. Geol. Soc. London 163*, 363–373.

Evans, D.A.D., Mitchell, R.N. 2011. Assembly and breakup of the core of Paleoproterozoic–Mesoproterozoic supercontinent Nuna. *Geology 39*, 443–446

Khain, E.V., Bibikova, E.V., Sal'nikova, E.B., Kröner, A., Gibsher, A. S., Didenko, A.N., Degtyarev, K.E., Fedotova, A.A. 2003. The Palaeo-Asian Ocean in the Neoproterozoic and early Palaeozoic: new geochronologic data and palaeotectonic reconstructions. *Precambrian Res. 122*, 329–358.

Li, Z.X., Bogdanova, S. V, Collins, A.S., Davidson, A., Waele, B. De, Ernst, R.E., Fitzsimons, I.C.W., Fuck, R.A., Gladkochub, D.P., Jacobs, J., Karlstrom, K.E. 2008. Assembly, configuration, and break-up history of Rodinia: a synthesis. *Precambrian Res. 160*, 179–210.

Nance, R.D., Murphy, J.B. 1994. Contrasting basement isotopic signatures and the palinspastic restoration of peripheral orogens: example from the Neoproterozoic Avalonian–Cadomian belt. *Geology 22*, 617–620.

Tait, J.A., Bachtadse, V., Franke, W., Soffel, H.C. 1997. Geodynamic evolution of the European Variscan fold belt: palaeomagnetic and geological constraints. *Int. J. Earth Sci. 86*, 585–598.

Andreev, A.A., Rytsk, E.Yu., Velikoslavinskii, S.D., Tolmacheva, E.V., Bogomolov, E.S., Lebedeva, Y.M., Fedoseenko, A.M. 2022. Age, composition, and tectonic setting of the formation of Late Neoproterozoic (Late Baikalian) complexes in the Kichera Zone, Baikal-Vitim Belt, Northern Baikal Area: Geological, geochronological, and Nd Isotope data. *Petrology*, 30, 337–368. https://doi.org/10.1134/S0869591122040026

Donskaya, T.V., Sklyarov, E.V., Gladkochub, D.P., Mazukabzov, A.M., Sal'nikova, E.B., Kovach, V.P., Yakovleva, S.Z., Berezhnaya, N.G. 2000.The Baikal collisional metamorphic belt. *Dokl. Earth Sci.*, 374, 1075—1079.

Fedorovsky, V.S., Donskaya, T.V., Gladkochub, D.P., Khromykh, S.V., Mazukabzov, A.M., Mekhonoshin, A.S., Sklyarov, E.V., Sukhorukov, V.P., Vladimirov, A.G., Volkova, N.I., Yudin, D.S. 2005. The Ol'khon collision system (Baikal region). In: Sklyarov E.V. (Ed.), Structural and Tectonic Correlation across the Central Asia Orogenic Collage: North-Eastern Segment. Institute of the Earth's Crust, Irkutsk, pp. 5—76 (in Russian).

Metelkin, D.V., Vernikovsky, V.A., Kazansky, A.Yu. 2012. Tectonic evolution of the Siberian paleocontinent from the Neoproterozoic to the Late Mesozoic: Paleomagnetic record and reconstructions. *Russ. Geol. Geophys.*, 53, 675–688. https://doi.org/10.1016/j.rgg.2012.05.006

Nozhkin, A.D., Turkina, O.M., Sovetov, Yu.K., Travin, A.V. 2007. The Vendian accretionary event in the southwestern margin of the Siberian Craton. *Dokl. Earth Sci.*, 415, 869–873. https://doi.org/10.1134/S1028334X07060098

Nozhkin, A.D., Dmitrieva, N.V., Likhanov, I.I., Serov, P.A., Kozlov, P.S. 2016. Geochemical, isotopic, and geochronological evidence for subsynchronous island-arc magmatism and terrigenous sedimentation (Predivinsk terrane of the Yenisei Ridge). *Russ. Geol. Geophys.*, 57, 1570–1590. https://doi.org/10.1016/j.rgg.2016.10.004

Rudnev, S.N. 2013. Early Paleozoic granitoid magmatism in the Altay-Sayan folded area and in the Lake zone in Western Mongolia. Izd. SO RAN, Novosibirsk (in Russian).

Ruzhentsev, S.V., Minina, O.R., Nekrasov, G E., Aristov, V.A., Golionko, B.G., Doronina, N.A., Lykhin, D.A. 2012. The Baikal-Vitim Fold System: Structure and geodynamic evolution. *Geotectonics*, 46, 87–110. https://doi.org/10.1134/S0016852112020033

Rytsk, E.Y., Kovach, V.P., Makeev, A.F., Bogomolov, E.S., Rizvanova, N.G. 2009.The eastern boundary of the Baikal collisional belt: Geological, geochronological, and Nd isotopic evidence. *Geotectonics*, 43, 264—273. https://doi.org/10.1134/S0016852109040025

Rytsk, E.Y., Kovach, V.P., Yarmolyuk, V.V., Kovalenko, V.I., Bogomolov, E.S., Kotov, A.B. 2011. Isotopic structure and evolution of the continental crust in the East Transbaikalian segment of the Central Asian Foldbelt. *Geotectonics*, 45, 349–377. https://doi.org/10.1134/S0016852111050037

Rytsk, E.Yu., Salnikova, E.B., Glebovitsky, V.A., Velikoslavinsky, S.D., Alekseev, I.A., Fedoseenko, A.M., Plotkina, Yu.V. 2017. The Vendian age of granodiorites and plagiogranites of the Tallainskii complex (Baikal–Muya Belt): U–Pb isotope data. *Dokl. Earth Sci.* 474, 569–573. https://doi.org/10.1134/S1028334X17050166

Sovetov, J.K. 2018. Sedimentology and stratigraphic correlation of Vendian deposits in the southwestern Siberian Craton: major contribution of an exocratonic clastic source to sedimentary systems. *Litosfera*, 18, 20–45 (in Russian, English abstract). https://doi.org/10.24930/1681-9004-2018-18-1-020-045

Antipin, V., Gerel, O., Perepelov, A., Odgerel, D., Zolboo, T., 2016. Late Paleozoic and Early Mesozoic rare-metal granites in Central Mongolia and Baikal region: review of geochemistry, possible magma sources and related mineralization. *Journal of Geosciences* 61, 105-125.

Gerel, O. Rare Metals: Tin, Tungsten, Molybdenum, Lithium, Tantalum and Niobium Deposits. In *Mineral Resources of Mongolia;* Gerel, O.; Pirajno, F.; Batkhishig, B.; Dostal, J. Eds. Springer, 2021, pp. 129-184.

Dostal, J., Kontak, D. J., Gerel, O., Gregory Shellnutt, J., & Fayek, M. 2015. Cretaceous ongonites (topaz-bearing albite-rich microleucogranites) from Ongon Khairkhan, Central Mongolia: Products of extreme magmatic fractionation and pervasive metasomatic fluid: Rock interaction. *Lithos*, *236-237*, 173-189. https://doi.org/10.1016/j.lithos.2015.08.003

Kovalenko, V.I., Kuzmin, M. I., Zonenshain, L, P., Nagibina, M.S., Pavlenko, A.S., Vladykin, N.V., Tseden, T., Gundsambuu, T.S., Goreglyad, A.V., 1971. *Rare-metal granitoids in Mongolia: petrology, distribution of rare elements.* Transactions 5, 1–239 (in Russian).

Heumann, M.J., Johnson, C.L., Webb, L.E., Taylor, J.P., Jalbaa, U., and Minjin, C., 2012. Paleogeographic reconstruction of a late Paleozoic arc collision zone, southern Mongolia, *Bull. Geol. Soc. Am. 124*, p. 1514–1534. doi.org/10.1130/B30510.1

Johnson, C.L., Amory, J.A., Graham, S.A., Lamb, M.A., Badarch, G. and Affolter, M., 2008. Accretionary tectonics and sedimentation during late Paleozoic arc collision, China-Mongolia border region. *Spec. Pap. Geol. Soc. Am, 436*, p. 363–390. doi.org/10.1130/2008.2436(16)

Stypula, M.J., and Webb, L.E., 2010. Microstructural and U-Pb Zircon Constraints on the Relationship between Partial Melting and Ductile Shear in the East Gobi Fault Zone, Southeast Mongolia. *EOS T Am Geophys Un., 10.* T23A-2243.

Taylor, J., Webb, L., Johnson, C., and Heumann, M., 2013.The lost South Gobi Microcontinent: protolith studies of metamorphic tectonites and implications for the evolution of continental crust in southeastern Mongolia, *Geosciences, 3*, p. 543–584, doi.org/10.3390/geosciences3030543

Chen, Y., Zhang, Z., Fanning, C. M., Yang, J., Fu, B., & Wu, T. (2017). Geochemistry and zircon U–Pb–Hf isotopic data for Permo-Carboniferous sediments in the Solonker zone, Inner Mongolia, China: Constraints on depositional age, provenance and tectonic setting. Journal of the Geological Society, 175(3), 543–559. https://doi.org/10.1144/jgs2017-079

Fu, D., Qian, Q., & Huang, B. (2025).Terminal subduction processes of the Paleo-Asian Ocean: Insights from podiform chromitites in the Solonker suture zone, southeastern central Asian orogenic belt. GSA Bulletin, 137(7–8), 3119–3140. https://doi.org/10.1130/B38176.1

Guy, A., Schulmann, K., Soejono, I., & Xiao, W. (2020). Revision of the Chinese Altai-East Junggar terrane accretion model based on geophysical and geological constraints. Tectonics, 39(4), Article e2019TC006026. https://doi.org/10.1029/2019TC006026

Jian, P., Liu, D., Kröner, A., Windley, B. F., Shi, Y., Zhang, W., Zhang, F., Miao, L., Zhang, L., & Tomurhuu, D. (2010b). Evolution of a Permian intraoceanic arc–trench system in the Solonker suture zone, central Asian orogenic belt, China and Mongolia. Lithos, 118(1–2), 169–190. https://doi.org/10.1016/j.lithos.2010.04.014

Kovach, V., Kozakov, I., Kröner, A., Salnikova, E., Wang, K.-L., Lee, H.-Y., Plotkina, J., Gorokhovsky, B., Adamskaya, E., Tolmacheva, E., & Shpakovich, L. (2021). Early Neoproterozoic crustal growth and microcontinent formation of the north–central central Asian orogenic belt: New geological, geochronological, and Nd–Hf isotopic data on the mélange zone within the Zavkhan terrane, western Mongolia. Gondwana Research, 91, 254–276. https://doi.org/10.1016/j.gr.2020.12.022

Kröner, A., Lehmann, J., Schulmann, K., Demoux, A., Lexa, O., Tomurhuu, D., Štípská, P., Liu, D., & Wingate, M.T. D. (2010). Lithostratigraphic and geochronological constraints on the evolution of the central Asian

orogenic belt in SW Mongolia: Early Paleozoic rifting followed by late Paleozoic accretion. American Journal of Science, 310(7), 523–574. https://doi.org/10.2475/07.2010.01

Miao, L., Baatar, M., Zhang, F., Anaad, C., Zhu, M., & Yang, S. (2016). Cambrian Kherlen ophiolite in northeastern Mongolia and its tectonic implications: SHRIMP zircon dating and geochemical constraints. Lithos, 261, 128–143. https://doi.org/10.1016/j.lithos.2015.12.012

Parfenov, L. M., Khanchuk, A. I., Badarch, G., Miller, R. J., Naumova, V. V., Nokleberg, W. J., Ogasawara, M., Prokopiev, A. V., & Yan, H. (2004). Northeast Asia geodynamic map (U.S. Geological Survey Open-File Report 2004-1050). U.S. Geological Survey.

Rippington, S., Cunningham, D., England, R., & Hendriks, B. (2013). The crustal assembly of southern Mongolia: New structural, lithological and geochronological data from the Nemegt and Altan ranges. Gondwana Research, 23(4), 1535–1553. https://doi.org/10.1016/j.gr.2012.09.001

Tomurtogoo, O. (2012). Tectonic subdivision of orogenic belt of Mongolia [in Mongolian]. Geology, 21(2), 5–25.

Xiao, W., Windley, B. F., Han, C., Liu, W., Wan, B., Zhang, J., Ao, S., Zhang, Z., & Song, D. (2018). Late Paleozoic to early Triassic multiple roll-back and oroclinal bending of the Mongolia collage in central Asia. Earth-Science Reviews, 186, 94–128. https://doi.org/10.1016/j.earscirev.2017.09.020

Zhu, M., Pastor–Galán, D., Miao, L., Zhang, F., Ganbat, A., Li, S., Yang, S., & Wang, Z. (2023a). Evidence for early Pennsylvanian subduction initiation in the Mongol–Okhotsk Ocean from the Adaatsag ophiolite (Mongolia). Lithos, 436–437, Article 106951. https://doi.org/10.1016/j.lithos.2022.106951

Zhu, M., Pastor–Galán, D., Tang, C., & Li, J. (2026). Early Carboniferous ophiolite discovery in central Mongolia: Expanding the record of subduction initiation in the Mongol-Okhotsk Ocean. GSA Bulletin. Advance online publication. https://doi.org/10.1130/B38935.1

Zhu, M., Wakabayashi, J., Pastor-Galán, D., Zhang, F., Ganbat, A., Miao, L., Yang, S., & Wang, Z. (2023b). Large-scale Permo-Triassic back-arc extensions of the Mongol-Okhotsk Ocean. GSA Bulletin, 135(11–12), 3121–3136. https://doi.org/10.1130/B36644.1

Zhu, M., Zhang, F., Miao, L., Baatar, M., Anaad, C., Yang, S., & Li, X. (2017). The late Carboniferous Khuhu Davaa ophiolite in northeastern Mongolia: Implications for the tectonic evolution of the Mongol–Okhotsk Ocean. Geological Journal, 53(4), 1263–1278. https://doi.org/10.1002/gj.2955

Jiang, Y., Štípská, P., Schulmann, K., Aguilar, C., Wang, S., Anczkiewicz, R., Chopin, F., et al. (2022). Barrovian and Buchan metamorphic series in the Chinese Altai: P–T–t–D evolution and tectonic implications. Journal Of Metamorphic Geology, 40(4), 823-857. doi: https://doi.org/10.1111/jmg.12647

Jiang, Y. D., Schulmann, K., Kröner, A., Sun, M., Lexa, O., Janoušek, V., Hanžl, P., et al. (2017). Neoproterozoic-Early Paleozoic Peri-Pacific Accretionary Evolution of the Mongolian Collage System: Insights from Geochemical and U-Pb Zircon Data from the Ordovician Sedimentary Wedge in the Mongolian Altai. Tectonics, 36(11), 2305-2331.

Jiang, Y. D., Schulmann, K., Sun, M., Štípská, P., Guy, A., Janoušek, V., et al. (2016). Anatexis of accretionary wedge, Pacific-type magmatism, and formation of vertically stratified continental crust in the Altai Orogenic Belt. Tectonics, 35(12), 3095-3118.

Jiang,Y. D., Schulmann, K., Sun, M., Weinberg, R. F., Štípská, P., Li, P. F., et al. (2019). Structural and Geochronological Constraints on Devonian Suprasubduction Tectonic Switching and Permian Collisional Dynamics in the Chinese Altai, Central Asia. Tectonics, 38(1), 253-280.

Kong, L., Jiang,Y., Schulmann, K., Zhang, J., Weinberg, R. F., Sun, M., et al. (2022). Petrostructural and Geochronological Constraints on Devonian Extension-Shortening Cycle in the Chinese Altai: Implications for Retreating-Advancing Subduction. Tectonics, 41(9), e2021TC007195.

Ma, J., Jiang,Y.,Yuan, C., Chen, M., Schulmann, K., Sun, M., et al. (2026). Early Carboniferous backarc basin in the Bidz ophiolitic terrane, Mongolia: Geochemical and geochronological constraints and tectonic implications. *GSA Bulletin*.

Wang, S., Jiang,Y., Weinberg, R., Schulmann, K., Zhang, J., Li, P., et al. (2021). Flow of Devonian anatectic crust in the accretionary Altai Orogenic Belt, central Asia: Insights into horizontal and vertical magma transfer. GSA Bulletin, 133 (11-12), 2501–2523. doi: https://doi.org/10.1130/B35645.1

Xiao, W. J., Windley, B. F., Yuan, C., Sun, M., Han, C. M., Lin, S. F., et al. (2009). Paleozoic multiple subduction-accretion processes of the southern Altaids. American Journal of Science, 309(3), 221-270.

Archibald, N., Gow, P. & Boschetti, F. 1999. Multiscale edge analysis of potential field data. Exploration Geophysics, 30, 38-44, https://doi.org/10.1071/EG999038.

Janoušek, V., Jiang,Y., Buriánek, D., Schulmann, K., Hanžl, P., Soejono, I., Kröner, A., Altanbaatar, B., Erban, V., Lexa, O., Ganchuluun,T. & Košler, J. 2018. Cambrian–Ordovician magmatism of the Ikh-Mongol Arc System exemplified by the Khantaishir Magmatic Complex (Lake Zone, south–central Mongolia). Gondwana Research, 54, 122-149, https://doi.org/10.1016/j.gr.2017.10.003.

Khain, E.V., Bibikova, E.V., Kröner, A., Zhuravlev, D.Z., Sklyarov, E.V., Fedotova, A.A. & Kravchenko-Berezhnoy, I.R. 2002.The most ancient ophiolite of the Central Asian fold belt: U-Pb and Pb-Pb zircon ages for the Dunzhugur Complex, Eastern Sayan, Siberia, and geodynamic implications. Earth and Planetary Science Letters, 199, 311-325, https://doi.org/10.1016/S0012-821X(02)00587-3.

Krýza, O., Lexa, O., Schulmann, K., Guy, A., Gapais, D., Cosgrove, J. & Xiao, W. 2021. Oroclinal buckling and associated lithospheric-scale material flow – insights from physical modelling: Implication for the Mongol-Hingan orocline.Tectonophysics, 800, 228712, doi: https://doi.org/10.1016/j.tecto.2020.228712.

Kuzmichev, A., Kröner, A., Hegner, E., Dunyi, L. &Yusheng, W. 2005.The Shishkhid ophiolite, northern Mongolia: A key to the reconstruction of a Neoproterozoic island-arc system in central Asia. Precambrian Research, 138, 125-150, https://doi.org/10.1016/j.precamres.2005.04.002.

Parfenov, L.M., Khanchuk, A.I., Badarch, G., Miller, R.J., Naumova, V.V., Nokleberg, W.J., Ogasawara, M., Prokopiev, A.V. & Yan, H. 2003. Preliminary Northeast Asia Geodynamics Map, https://doi.org/10.3133/ofr03205.

Schulmann, K., Edel, J.B., Lexa, O., Xiao, W.,Třebínová, D., Spikings, R., Schaltegger, U., Derkowski, A. & Szczerba, M. 2023. Paleomagnetic, tectonic and geochronological constraints for Permian–Triassic oroclinal bending of the Mongolian collage. National Science Review, 10, https://doi.org/10.1093/nsr/nwac184.

Shatsky, V.S., Malkovets, V.G., Belousova, E.A. & Skuzovatov, S.Y. 2015. Evolution history of the Neoproterozoic eclogite-bearing complex of the Muya dome (Central Asian Orogenic Belt): Constraints

from zircon U–Pb age, Hf and whole-rock Nd isotopes. Precambrian Research, 261, 1-11, https://doi.org/10.1016/j.precamres.2015.01.013.

Štípská, P., Schulmann, K., Lehmann, J., Corsini, M., Lexa, O. & Tomurhuu, D. 2010. Early Cambrian eclogites in SW Mongolia: Evidence that the Palaeo-Asian Ocean suture extends further east than expected. Journal of Metamorphic Geology, 28, 915-933, https://doi.org/10.1111/j.1525-1314.2010.00899.x.

Vallée, M.A., Keating, P., Smith, R.S. & St-Hilaire, C. 2004. Estimating depth and model type using the continuous wavelet transform of magnetic data. Geophysics, 69, 191-199, https://doi.org/10.1190/1.1649387.

Barry, T.L., Saunders, A.D., Kempton, P.D., Windley, B.F., Pringle, M.S., Dorjnamjaa, D., Saandar, S. 2003. Petrogenesis of Cenozoic basalts from Mongolia: Evidence for the role of asthenospheric versus lithospheric mantle sources. *J. of Petrol.*, 44(1). 55–91. https://doi.org/10.1093/petrology/44.1.55.

Comeau, M. J., Käufl, J. S., Becken, M., Kuvshinov, A., Grayver, A. V., Kamm, J., Demberel, S., Sukhbaatar, U., Batmagnai, E. 2018. Evidence for fluid and melt generation in response to an asthenospheric upwelling beneath the Hangai Dome. *Mong. Earth and Planet. Sci. Lett.* 487 (1), 201–209. https://doi.org/10.1016/j.epsl.2018.02.007.

Cunningham, D. 2001. Cenozoic normal faulting and regional doming in the southern Hangay region, central Mongolia: Implications for the origin of the Baikal rift province. *Tectonophysics*, 331(4). 389–411. https://doi.org/10.1016/S0040-1951(00)00228-6

Feng, L. 2021. High-resolution crustaland uppermost mantle structurebeneath central Mongolia fromRayleigh waves and receiver functions. *J. Geophys. Res. Solid Earth*, 126, e2020JB021161. https://doi.org/10.1029/2020JB021161

He, J., Wu, Q., Sandvol, E., Ni, J., Gallegos, A., Gao, M., et al. 2016.The crustal structure of south-central Mongolia using receiver functions. *Tectonics*, 35, 1392–1403. https://doi.org/10.1002/2015TC004027

Herzberg, C. 2011. Identification of Source Lithology in the Hawaiian and Canary Islands: Implications for Origins. *J. Petrol*. 52(1). 113–146. doi:10.1093/petrology/egq075

Huang, Z., Zhao, D. 2022. Seismotectonics of Mongolia and Baikal rift zone controlled by lithospheric structures. *Geophys. Res. Lett.*, 49. e2022GL099525. https://doi.org/10.1029/2022GL099525

Ivanov, A. V., Demonterova, E. I., He, H., Perepelov, A. B., Travin, A. V., Lebedev, V. A. 2015. Volcanism in the Baikal rift: 40 years of active-versus-passive model discussion. *Earth-Sci. Rev.* (148). 18–43. https://doi.org/10.1016/j.earscirev.2015.05.011.

Jiang, M., Bao, X., Wang, T., Wu, Y., Zhou, K., Li, X. 2026. Inherited lithospheric structure controls Cenozoic intraplate basaltic volcanism in central Mongolia due to mantle upwelling. *J. Geophys. Res. Solid Earth*, 131. e2025JB031727. https://doi.org/10.1029/2025JB031727

Lambart, S., Baker, M. B., Stolper, E. M. 2016.The role of pyroxenite in basalt genesis: Melt-PX, a melting parameterization for mantle pyroxenites between 0.9 and 5 GPa. *J. Geophys. Res. Solid Earth*, 121(8). 5708–5735. doi:10.1002/ 2015JB012762.

Petit, C., Déverchère, J., Calais, E., San'kov, V., Fairhead, D. 2002. Deep structure and mechanical behavior of the litho-sphere in the Hangai-Hövsgöl region, Mongolia: New con-straints from gravity modelling. *Earth Planet. Sci. Lett.*, 197(3–4). 133–149. doi:10.1016/S0012-821X(02)00470-3.

Savatenkov, V. M., Yarmolyuk, V. V., Kudryashova, E. A., Kozlovskii, A. M., 2010. Sources and geodynamics of the Late Cenozoic volcanism of Central Mongolia: evidence from isotope-geochemical studies. *Petrol.* 18 (3), 278–307.

Sheldrick, T. C., Hahn, G., Ducea, M. N., Stoica, A. M., Constenius, K., Heizler, M., 2020. Peridotite versus pyroxenite input in Mongolian Mesozoic-Cenozoic lavas, and dykes. *Lithos*, 376–377. https://doi.org/10.1016/j.lithos.2020.105747.

Tiberi, C., Deschamps, A., Déverchère, J., Petit, C., Perrot, J., Appriou, D., et al. 2008. Asthenospheric imprints on the lithosphere in Central Mongolia and Southern Siberia from a joint inversion of gravity and seismology (MOBAL experiment). *Geophys. J. Int.* 175 (3). 1283–1297. doi:10.1111/j.1365-246x.2008.03947.x

Vinnik, L. P., Delitsyna, L. L., Makeyeva, L. I., and Oreshin, S. I. 2024. Deep Structure of the Baikal Rift Zone and Central Mongolia. *Phys. Solid Earth.*, 60(2). 179–188. https://doi.org/10.31857/S0002333724020014

Walker, R.T., Nissen, E., Molor, E., Bayasgalan, A., 2007, Reinterpretation of the active faulting in central Mongolia. *Geol.*, 35. 759–762. https://doi.org/10.1130/G23716A.1

Windley, B. F., Allen, M. B. 1993. Mongolian Plateau: Evidence for a late Cenozoic mantle plume? *Geol.*, 21(4), p.295. 10.1130/0091-7613(1993)021<0295:MPEFAL>2.3.CO;2

Xu, M., Wang, K., Chen, J., He, J., Liu, Q., Liu, Y., et al. 2025. Multilevel mechanisms driving intraplate volcanism in central Mongolia revealed by adjoint waveform tomograph and ambient noise data. *Earth Planet. Sci. Lett.*, 650. 119137. https://doi.org/10.1016/j.epsl.2024.119137

Yarmolyuk, V. V., Kudryashova, E. A., Kozlovsky, A. M., Lebedev, V. A., Savatenkov, V. A., 2015. Late Mesozoic-Cenozoic intraplate magmatism in Central Asia and its relation with mantle diapirism: evidence from the south Khangai volcanic region, Mongolia. *J. Asian Earth Sci.* 111. 604–623. https://doi.org/10.1016/j. jseaes.2015.05.008

Yang, Z.-F., Li, J., Jiang, Q.-B., Xu, F., Guo, S.-Y., Li, Y., Zhang, J. 2019. Using major element logratios to recognize compositional patterns of basalt: Implications for source lithological and compositional heterogeneities. *J. Geophys. Res: Solid Earth.*, 124. 3458–3490.

Zorin, Y. A., Novoselova, M. R., Turutanov, E. K., Kozhevnikov, V. M. 1990. Structure of the lithosphere of the Mongolian-Siberian mountainous province. *J. Geodyn.,* 11. 327–342.

Arzhannikova, A. V., Demonterova, E. I., Jolivet, M., Arzhannikov, S. G., Mikheeva, E. A., Ivanov, A. V., Khubanov, V. B., & Pavlova, L. A. (2020). Late Mesozoic topographic evolution of western Transbaikalia: Evidence for rapid geodynamic changes from the Mongol–Okhotsk collision to widespread rifting. Geoscience Frontiers, 11(5), 1695–1709. https://doi.org/10.1016/j.gsf.2019.12.012

Daoudene, Y., Gapais, D., Cogné, J.-P., & Ruffet, G. (2017). Late Jurassic – Early Cretaceous continental extension in northeast Asia – Relationships to plate kinematics. Bulletin de La Société Géologique de France, 188(1–2), 10. https://doi.org/10.1051/bsgf/2017011

Jolivet, M., Arzhannikova, A., Frolov, A., Arzhannikov, S. G., Kulagina, N., Akulova, V., & Vassallo, R. (2017). Late Jurassic - Early Cretaceous paleoenvironmental evolution of the Transbaikal basins (SE Siberia): Implications for the Mongol-Okhotsk orogeny. Bulletin de La Societe Geologique de France, 188, 101–118. https://doi.org/10.1051/bsgf/2017010

Henriquez, S; Johnson, C.; Tully, J.; Lippert, P.; Webb, L.; Ochir, G. (2023). The growth of the Mongol-Okhotsk Belt in central Mongolia: Insights from low-temperature thermochronology. Poster. Thermo Conference.

Jepson, G., Carrapa, B., Gillespie, J., Feng, R., DeCelles, P. G., Kapp, P., Tabor, C. R., & Zhu, J. (2021). Climate as the Great Equalizer of Continental-Scale Erosion. Geophysical Research Letters, 48(20), e2021GL095008. https://doi.org/10.1029/2021GL095008

Khukhuudei, U., Kusky, T., Windley, B. F., Otgonbayar, O., Wang, L., Nie, J., Xiao, W., Zhang, L., & Song, X. (2024). Cenozoic intracontinental tectonics of Mongolia and its climate effects: A synthesized review. Earth-Science Reviews, 258, 104934. https://doi.org/10.1016/j.earscirev.2024.104934

Feng, Z., Jia, Z., Xie, X., et al., 2010. Tectonostratigraphic units and stratigraphic sequences of the nonmarine Songliao basin, northeast China. Basin Research. doi.org/10.1111/j.1365-2117.2009.00 445.x.

Gao, Y., Ibarra, D.E., Caves Rugenstein, J.K., et al., 2021. Terrestrial climate in mid-latitude East Asia from the latest Cretaceous to the earliest Paleogene: A multiproxy record from the Songliao Basin in northeastern China. Earth-Science Reviews. doi.org/10.1016/j.earscirev.2021.103572.

Gao, Y., Wang, C., Wang, P., et al., 2019. Progress on Continental Scientific Drilling Project of Cretaceous Songliao Basin (SK-1 and SK-2). Science Bulletin. doi.org/10.1016/j.scib.2018.12.017.

Gu, X., Zhang, L., Yin, R., et al., 2022. Deccan volcanic activity and its links to the end-Cretaceous extinction in northern China. Global and Planetary Change. doi.org/10.1016/j.gloplach a.2022.103772.

Huang, H., Gao, Y., Ma, C., et al., 2021. Organic carbon burial is paced by a ~173-ka obliquity cycle in the middle to high latitudes. Science Advances. doi.org/10.1126/sciadv.abf9489.

Liu, H., Wang, P., Gao, Y., et al., 2020. New data from ICDP borehole SK2 and its constraint on the beginning of the lower cretaceous shahezi formation in the songliao basin, NE china. Science Bulletin. doi.org/10.1016/j.scib.2020.12.002.

Miller, K.G., Kominz, M.A., Browning, J.V., et al., 2005. The Phanerozoic Record of Global Sea-Level Change. Science. doi.org/10.1126/science.Khuk.

Tierney, J.E., Poulsen, C.J., Montañez, I.P., et al., 2020. Past climates inform our future. Science. doi.org/10.1126/science.aay3701.

Wang, C., Scott, R.W., Wan, X., et al., 2013. Late Cretaceous climate changes recorded in Eastern Asian lacustrine deposits and North American Epieric sea strata. Earth-Science Reviews. doi.org/10.1016/j.earscirev.2013.08.016.

Wang, C., Gao, Y., Wang, P., et al. 2024. International Continental Scientific Drilling Project of the Songliao Basin: Terrestrial geological records of the Cretaceous dinosaur age. Earth Science Frontiers, 2024, 31(1): 412-430.3. https://doi.org/10.13745/j.esf.sf.2024.1.4.

Zhang, L., Wang, C., Wignall, P.B., et al., 2018. Deccan volcanism caused coupled pCO2 and terrestrial temperature rises, and pre-impact extinctions in northern China. Geology. doi.org/10.113 0/g39992.1.

Meng, Q.-R., Zhou, Z.-H., Zhu, R.-X., Xu, Y.-G., & Guo, Z.-T. (2022). Cretaceous basin evolution in northeast Asia: Tectonic responses to the paleo-Pacific plate subduction. National Science Review, 9(1), nwab088. https://doi.org/10.1093/nsr/nwab088

Tully, J. E., Johnson, C. L., Graham, S. A., Cope, T., & Ritts, B. D. (2024). Sedimentary basins of the late Mesozoic extensional domain of China and Mongolia. *In Regional Geology and Tectonics*. 205–221. Elsevier. https://doi.org/10.1016/B978-0-444-64136-6.00002-6

Wang, T., Tong, Y., Xiao, W., Guo, L., Windley, B. F., Donskaya, T., Li, S., Tserendash, N., & Zhang, J. (2021). Rollback, scissor-like closure of the Mongol-Okhotsk Ocean and formation of an orocline: Magmatic migration based on a large archive of age data. *National Science Review*, nwab210. https://doi.org/10.1093/nsr/nwab210

Yang, Y.-T., Guo, Z.-X., Song, C.-C., Li, X.-B., & He, S. (2015). A short-lived but significant Mongol–Okhotsk collisional orogeny in latest Jurassic–earliest Cretaceous. *Gondwana Research*, 28(3), 1096–1116. https://doi.org/10.1016/j.gr.2014.09.010

Bartley, J.M., and Fletcher, J.M., 1990, Tertiary extension and contraction of lower-plate rocks in the Central Mojave Metamorphic Core Complex, southern California: Tectonics, v. 9, p. 521–534.

Coney, P.J., 1980, Cordilleran metamorphic core comlexes: An Overview: GSA Mem., v. 153, p. 7–31.

Daoudene, Y., Ruffet, G., Cocherie, A., Ledru, P., and Gapais, D., 2013, Timing of exhumation of the Ereendavaa metamorphic core complex (north-eastern Mongolia)- U-Pb and 40 Ar/ 39 Ar constraints: Journal of Asian Earth Sciences, v. 62, p. 98–116, doi:10.1016/j.jseaes.2011.04.009.

Donskaya, T. V., Windley, B.F., Mazukabzov, A.M., Kröner, A., Sklyarov, E. V., Gladkochub, D.P., Ponomarchuk, V.A., Badarch, G., Reichow, M.K., and Hegner, E., 2008, Age and evolution of late Mesozoic metamorphic core complexes in southern Siberia and northern Mongolia: Journal of the Geological Society, London, v. 165, p. 405–421, doi:10.1144/0016-76492006-162.

Graham, S.A., Hendrix, M.S., Johnson, C.L., Badamgarav, D., Badarch, G., Amory, J., Porter, M., Barsbold, R., Webb, L.E., and Hacker, B.R., 2001, Sedimentary record and tectonic implications of Mesozoic rifting in southeast Mongolia: Geol. Soc. Am. Bull., v. 113, p. 1560–1579, doi:10.1130/0016-7606(2001)113<1560:SRATIO>2.0.CO;2.

Miao, L., Zhang, F., Baatar, M., Zhu, M., and Anaad, C., 2017, SHRIMP zircon U-Pb ages and tectonic implications of igneous events in the Ereendavaa metamorphic terrane in NE Mongolia: Journal of Asian Earth Sciences.

Petrov, O.V., Leonov, Y.G., Tingdong, L., and Tomurtogoo, O., 2014, Tectonic Map of Northern, Central and Eastern Asia and Adjacent Areas: Russian Geological Research Institute, Geological Institute of the Russian Academy of Sciences, https://ccgm.org/en/product/tectonic-map-of-the-north-central-and-eastern-asia-and-neighbouring-regions/.

Van Der Voo, R., Van Hinsbergen, D.J.J., Domeier, M., Spakman, W., and Torsvik, T.H., 2015, Latest Jurassic-earliest Cretaceous closure of the Mongol-Okhotsk Ocean: A paleomagnetic and seismological-tomographic analysis: GSA Spec. Pap., v. 513, p. 589–606, doi:10.1130/2015.2513(19).

Wang, T., Zheng, Y., Zhang, J., Zeng, L., Donskaya, T., Guo, L., and Li, J., 2011, Pattern and kinematic polarity of late Mesozoic extension in continental NE Asia: Perspectives from metamorphic core complexes: Tectonics, v. 30, doi:10.1029/2011TC002896.

Whitney, D.L., Teyssier, C., Rey, P., and Roger Buck, W., 2013, Continental and oceanic core complexes: *Geol. Soc. Am. Bull.*, v. 125, p. 273–298, doi:10.1130/B30754.1.

Zorin, Y.A., 1999, Geodynamics of the western part of the Mongolia-Okhotsk collisional belt, Trans-Baikal region (Russia) and Mongolia: Tectonophysics, v. 306, p. 33–56, doi:10.1016/S0040-1951(99)00042-6.

Bobrowski P., Jórdecza M., Masojć M., Gunchinsuren B., Goslar T., Muntowski P., Odsuren D., Szmit M., Bazangur D., Michalec G., Szykulski J., Gankhuyag O., Sikora R., 2025. The earliest Holocene wanderers through the Gobidesert evidenced by the radiocarbon chronology of the lakeshore settlement near the Tsakhiurtyn Hondi, Mongolia. Radiocarbon. https://doi: 10.1017/RDC.2025.4.

Masojć M., Gunchinsuren B., Szykulski J., Sikora, R., Dashzeveg B., Gałaś R., Odsuren D., Wójcik A., Michalec G., Szmit M., Gankhuyag O., Osypińska M., Namjilmaa E., 2024. Paleolakes and caves around Tsakhirutyn Hundi (Flint Valley) – Pleistocene and Holocene settlement in the borderland between the Gobi-Altai Mountains and the Gobi Desert, Mongolia. Antiquity 98, (399): e15. https://doi:10.15184/aqy.2024.44.

Masojć M., Gunchinsuren B., Szykulski J., Bobrowski P., Jórdeczka M., Dashzeveg B., Sikora, R., Michalec G., Muntowski P., Davaakhuu O., Szmit M., Gałaś A., Wójcik A., Namjilmaa, E., 2025 – Stone age societies in the borderland between the Gobi-Altai Mountains and the Gobi Desert, Mongolia. *Studia Archaeologica*. 5-12. https://doi.org/10.5564/sa.v48i2.4730.

Masojć M., Nowaczewska W., Zanolli C., Gunchinsuren B., Michalec G., Khatsenovich A.M., Douka K., Sikora R., Bazargur D., Leszczyński B., Wróbel A., Odsuren D., Szykulski J., Szmit M., Namjilmaa E., 2026. A Late Pleistocene human tooth from Khutul Usny Cave (FV 8), Mongolia – New evidence for early occupation of Eastern Central Asia by Homo sapiens. Quaternary Science Reviews, 383, https://doi.org/10.1016/j.quascirev.2026.109994.

Michalec G., Sikora R., Winiarska-Kabacińska M., Odsuren D., Wójcik A., Moska P., Szmit M., Bazangur D., Bobrowski P., Jórdeczka M., Szykulski J., Muntowski P., Gałaś A., Gunchinsuren B., Masojć M., 2025. Geoarchaeological research on site formation process, paleoenvironment, and human behaviors in the Early Holocene of the Gobi Desert, Mongolia. Plos One. https://doi:10.1371/journal.pone.0330209.

Sikora R., Wójcik A., Masojć M., Michalec G., Gunchinsuren B., Szmit M., Szykulski J., 2024 – Structural and paleoseismic conditions of rockfalls and cave collapse in the Khutul Usny valley (Arts Bogd Massif, CAOB, Mongolia). [In: Sikora R., Olkowicz M, Adamuszek M., 2024., Eds] 20th Jubilee Meeting of the Central European Tectonic Studies Groups. 24-27 April, 2024, Srebrna Góra. Abstract Book & Field Trip Guide, 55.

Sikora R., Wójcik A., Gałaś A., Wójcik-Tabol P., Michalec G., Gunchinsuren B., Masojć M., 2025 – Geological and geomorphological conditions of the lake reservoirs development in the southern margin of the Arts Bogd massif (Gobi-Altai Range, Mongolia). Geological Quarterly 69 (4), 1–23. https://doi.org/10.7306/gq.1818.

Sikora R., Masojć M., Wójcik A., Wójcik-Tabol O., Gałaś A., Pawłowski D., Michalec G., Moska O., Makohonienko M., Szykulski J., Kim J.C., Kwon J., Gunchinsuren B., 2026 – Sedimentological characteristics of four palaeolakes in the Tsakhiurtyn Hundi Lakeland (Gobi Desert, Mongolia). Quaternary International. https://doi.org/758. 10.1016/j.quaint.2026.110127.

Leipe, C., Handfried, D., Long,T., Heinrich, I., Hoelzmann, P., Mingram, J.,Tjallingii, R., Vrijmoed, J.C., Wagner, M.,Tarasov, P.E. 2025. Microfacies analysis and varve-based chronology reveal a variable 14C reservoir effect in Lake Shira, northern Inner Asia, over the past 2500 years. *Quat. Sci. Adv.*, 19, 100299. https://doi.org/10.1016/j.qsa.2025.100299

Leipe, C., Nykamp, M., Hoelzmann, P., Handfried, D., Shchetnikov, A.A., Bezrukova, E.V., Wagner, M., Tarasov, P.E. 2026. High-resolution hydroclimatic variability in northern Inner Asia in response to North Atlantic temperature changes during the last 2500 years. *Glob. Planet. Change*, 261, 105426. https://doi.org/10.1016/j.gloplacha.2026.105426

Asimus, J., Daczko, N. et al., 2024. Experimental replacement of zircon by melt-mediated coupled dissolution-precipitation causes dispersion in U–Pb ages. *J. Metamorph. Geol*. 42, 1179-1195

Corfu, F., Hanchar, J.M. et al., 2003. Atlas of zircon textures. Rev. Mineral. Geochem. 53, 469-500. Daczko, N.R., Elliott, V. et al., 2024. Zircon coupled dissolution-precipitation replacement during melt-rock interaction modifies chemical signatures resulting in misleading ages. *J. Metamorph. Geol*. 42, 1197-1214

Geisler,T., Schaltegger, U.,Tomaschek, F., 2007. Re-equilibration of zircon in aqueous fluids and melts. *Elements* 3, 43-50

Halpin, J.A., Daczko, N.R., Direen, N.G., Mulder, J.A., Murphy, R.C., Ishihara,T., 2020. Provenance of rifted continental crust at the nexus of East Gondwana breakup. *Lithos* 354

Halpin, J.A., Daczko, N.R. et al., 2012. Decoding near-concordant U-Pb zircon ages spanning several hundred million years: recrystallisation, metamictisation or diffusion? *Contrib. Mineral. Petrol*. 163, 67-85

Harlov, D.E., Anczkiewicz, R., Dunkley, D.J., 2023. Metasomatic alteration of zircon at lower crustal P-T conditions utilizing alkali- and F-bearing fluids:Trace element incorporation, depletion, and resetting the zircon geochronometer. *Geochim. Cosmochim. Acta*. 352, 222-235

Hoskin, P.W.O., Black, L.P., 2000. Metamorphic zircon formation by solid-state recrystallization of protolith igneous zircon. *J. Metamorph. Geol*. 18, 423-439

Kelsey, D.E., Clark, C., Hand, M., 2008.Thermobarometric modelling of zircon and monazite growth in melt-bearing systems: Examples using model metapelitic and metapsammitic granulites. *J. Met. Geol*. 26, 199-212

Kelsey, D.E., Powell, R., 2011. Progress in linking accessory mineral growth and breakdown to major mineral evolution in metamorphic rocks: A thermodynamic approach in the Na 2O-CaO-K 2O-FeO-MgO-Al2O3-SiO2-H2O-TiO2-ZrO2 system. *J. Metamorph. Geol*. 29, 151-166

Yildirim, O., Benesch, J., and Wang, J. 2026. Assessment of Geothermal Energy Resources in the Marcellus Shale. *J. of Geoenergy Science and Engineering*, Vol. 257, Part A: 214166.1-15, https://doi.org/10.1016/j.geoen.2025.214166.

Putnis, A., 2009. Mineral replacement reactions. *Rev. Mineral. Geochem*. 70, 87-124

Rubatto, D., 2017. Zircon:The metamorphic mineral. *Rev. Mineral. Geochem*. 83, 261-295

Spier, C.A., Daczko, N.R., Zhou, R.J., 2024. Zircon coupled dissolution-precipitation textures distinguish xenocrystic cargo from rare magmatic zircon in the Paleoarchean Bacuri mafic-ultramafic layered complex, *Precambrian Res*. 404

Spier, C.A., Ferreira, C.F., Daczko, N., 2022. Zircon U-Pb isotopic and geochemical study of metanorites from the chromite-mineralised Bacuri Mafic-Ultramafic Complex: Insights of a Paleoarchean crust in the Amapa Block, Guyana Shield, *Gondwana Res*. 105, 262-289

Štípská, P., Collett, C. et al. 2026. Melt-mediated coupled dissolution-precipitation of zircon in metagranite, Bohemian Massif. Contributions to Mineralogy and Petrology, 10.1007/s00410-026-02296-y

Wang,Y., Gao, P. et al., 2024. Zircon Hf isotope behavior during the magmatic-hydrothermal processes: A case from theYashan South China. *Lithos*. 470.

Feng, L. (2021). High-Resolution Crustal and Uppermost Mantle Structure Beneath Central Mongolia from Rayleigh Waves and Receiver Functions. *Journal of Geophysical Research: Solid Earth*, 126(4). https://doi.org/10.1029/2020JB021161

Ganbat, B.,Yoshizawa, K., Sodnomsambuu, D., & Munkhuu, U. (2024). Upper mantle structure beneath the Mongolian region from multimode surface waves: Implications for the western margin of Amurian plate. *Tectonophysics*, 890. https://doi.org/10.1016/j.tecto.2024.230506

Tarantola, A., & Valette, B. (1982). Generalized nonlinear inverse problems solved using the least squares criterion. *Reviews of Geophysics*, 20(2), 219–232. https://doi.org/10.1029/RG020i002p00219

Yoshizawa, K., & Kennett, B. L. N. (2002). Non-linear waveform inversion for surface waves with a neighbourhood algorithm-application to multimode dispersion measurements. *Geophysical Journal International*, 149(1), 118–133. https://doi.org/10.1046/j.1365-246X.2002.01634.x

Yoshizawa, K., & Kennett, B. L. N. (2004). Multimode surface wave tomography for the Australian region using a three-stage approach incorporating finite frequency effects. *Journal of Geophysical Research: Solid Earth*, 109(B2). https://doi.org/10.1029/2002jb002254

Zhao, H.,Wang, P., & Huang, Z. (2021). Lithospheric structures beneath the western Mongolian Plateau: Insight from S wave receiver function. *Journal of Asian Earth Sciences*, 212, 104733. https://doi.org/10.1016/j.jseaes.2021.104733

Zonenshain, L. P., & Savostin, L. A. (1981). Geodynamics of the Baikal rift zone and plate tectonics of Asia. *Tectonophysics*, 76(1–2), 1–45. https://doi.org/10.1016/0040-1951(81)90251-1

Click or tap here to enter text.Cai, Z.H., Xu, Z.Q., He, B.Z., & Wang, R.R. 2012. Age and tectonic evolution of ductile shear zones in the easternTianshan-Beishan orogenic belt. Acta Petrol. Sin., 28(06), 1875–1895.

Jiang, H.B.,Yang, H.Q.,Tan,W.J., Dong, F.C., Zhao, G.B., Ren, H.N., & Jia, J. 2014. Relationship between metallogenic series and geological formations in the central part of the EastTianshan–Beishan region. Bull. Mineral. Petrol. Geochem., 33(02), 262–270.

Xiao,W.J., Zhang, L.C., Qin, K.Z., Sun, S., & Li, J.L. 2004. Paleozoic accretionary and collisional tectonics of the EasternTianshan (China): implications for the continental growth of central Asia. Am. J. Sci., 304(04), 370–395.

Guy A., Schulmann K., Soejono I., Holzrichter N., Lexa O., Munchy M., 2021. Structures and geodynamics of the Mongolian tract of the Central Asian Orogenic Belt constrained by potential field analyses. *Gondwana Research,* 92, 26-53.

Levashova N. M., Kalugin V. M., Gibsher A. S., Yff J., Ryabinin A. B., Meert J. G., Malone S., 2010. The origin of the Baydaric microcontinent, Mongolia: Constraints from paleomagnetism and geochronology. *Tectonophysics* (485), 306-320.

Štípská P., Peřestý V., Soejono I., Schulmann K., Kylander-Clark R. C., Aguillar C., Collett S., Racek M., Mitova J., Dorjsuren O., Novotna N., 2023. Anticlockwise metamorphic paths at ca. 890–790 Ma from the NE Baidrag block, Mongolia, indicate back-arc compression at the Rodinia periphery. *Geoscience Frontiers* (14), 1-28.

Karpinsky Institute. 2025. Technology for Field Geological Documentation "SHERPA": User Guide. Saint Petersburg.

Antipin, V.S., Kuzmin, M.I., Odgerel, D., Kushch, L.V., Sheptyakova, N.V., 2022. Rare-metal Li-F granites in the Late Paleozoic, Early Mesozoic, and Late Mesozoic magmatic areas of Central Asia. *Russian Geology and Geophysics* 63, 772-788. https://doi.org/10.2113/RGG20214409

Beus, A.A., Severov, V.A., Sitnin, A.A., & Subbotin, K.D. 1962. *Albitized and Greisenized Granites (Apogranites).* Moscow: Academy of Sciences of the USSR (In Russian).

Kovalenko, V.I., Koval, P.V.,1984. Endogenic rare earths and rare metal formations of Mongolia. In *Endogenic ore formations of Mongolia*. M. Nauka, 50-75 (In Russian).

Tauson, L.V. (1977). *Geochemical Types and Ore-Bearing Potential of Granitoids.* Nauka, Moscow. (in Russian).

Yarmolyuk, V. V., Kuzmin, M. I., Kozlovsky, A. M., 2013. Late Paleozoic-Early Mesozoic within-plate magmatism in North Asia: traps, rifts, giant batholiths, and the geodynamics of their origin. *Petrology* 21, 101–126

Zonenshain, L.P., Kuzmin, M.I., & Natapov, L.M. 1990. *Geology of the USSR: A Plate-Tectonic Synthesis*. Geodynamics Series, Vol. 21. American Geophysical Union, Washington, D.C., 242 p.

Dorofeyuk, N.I. and Tarasov, P.E. (1998) Vegetation and lake levels in Northern Mongolia in the last 12,500 years as indicated by data of pollen and diatom analyses: Stratigraphy and Geological Correlation, 6, 70-83. (in Russian)

Grunert, J., Lehmkuhl, F. and Walther, M. (2000) Paleoclimatic evolution of the Uvs Nuur basin and adjacent areas (Western Mongolia): Quaternary International, 65/66, 171-191.

Krivonogov S.K., Sheinkman V.S. and Mistruykov A.A. (2005) Stages in the development of the Darhad dammed lake (Northern Mongolia) during the Late Pleistocene and Holocene: Quaternary International, 136, 83-94.

Krivonogov S.K., S.Yi., Kashiwaya K., Kim J.C., Narantsetseg T., Oyunchimeg T., Safonova I.Y., Kazansky A.Y., Sitnikova T., Kim J.Y. and Hasebe N. (2012) Solved and unsolved problems of sedimentation, glaciation and paleolakes of the Darhad Basin, Northern Mongolia: Quaternary Science Reviews, 56, 142-163.

Oyunchimeg, Ts., Tomurkuu, D. and Narantsetseg, Ts. (2003) The sedimentation condition and climate

change of Hovsgol basin using by chemical methods: Institute of Geology and Mineral Resources of MAS. No16, 135-147 (in Mongolian)

Oyunchimeg,Ts., Ariunbileg, S., Narantsetseg,Ts., Dolgorsuren, Kh. and Krivonogov, S.K. (2013). Lithology of Khyargas Nuur and petrochemical features: Khaiguulchin, 48, 132-140 (in Mongolian)

Prokopenko, A.A., Khursevich, G.K., Kuzmin, M.I., and Kawai,T. (2009) Productivity cycles in Lake Hovsgol, NW Mongolia, during the last 1Ma and the age model of the HDP-04 drill core: Quaternary. Intnternational., 205, 111-125.

Sun, A., Feng, Z., Ran, M. and Zhang, C. (2013) Pollen-recorded bioclimatic variations of the last ～22,600 years retrieved from Achit Nuur core in the western Mongolian Plateau: Quaternary International, 311, 36-43.

Burenjargal, U., Okamoto, A., Tsuchiya, N., Uno, M., Horie, K., Hokada, T. (2016). Contrasting geochemical signatures of Devonian and Permian granitoids from the Tseel Terrane, SW Mongolia. *J. Geosci.*, 61, 51–66. doi:10.3190/jgeosci.210

Buriánek, D., Soejono, I., Schulmann, K., Janoušek, V., Hanžl, P., Čáp, P., Bold, U., Svojtka, M., Collett, S., & Žáček, V. (2022). Subduction-controlled temporal and spatial variations in early Palaeozoic sedimentary and volcanic record of the Mongol-Altai Domain. *J. Asian Earth Sci.,* 230, 105182. doi:10.1016/j.jseaes.2022.105182

Cui, X., Cawood, P. A., Sun, M., Zhao, G. (2024). Recognizing big mantle wedges in deep time: Constraints from the Western Mongolia Collage in Central Asia. *Geology,* 52, 341–346. doi:10.1130/G51841.1

de Hoÿm de Marien, L., Janoušek, V., Schulmann, K., Hanžl, P., Míková, J., Hora, J. M., Racek, M., Lexa, O., Sukhbaatar, T., Buriánek, D., Aguilar, C. (2025). Middle Devonian–Carboniferous crustal differentiation promoted by hydrous plume-related magmatism along the Paleo-Pacific active margin: A case study of the Gashun Nuur Complex in the Mongolian Altai. *Gondwana Res.*, 147, 36–62. doi:10.1016/j.gr.2025.05.025

Hanžl, P., Schulmann, K., Janoušek, V., Lexa, O., Hrdličková, K., Jiang, Y., Buriánek, D., Altanbaatar, B., Ganchuluun, T., Erban, V. (2016). Making continental crust: Origin of Devonian orthogneisses from SE Mongolian Altai. *J. Geosci.*, 61, 25–50. doi:10.3190/jgeosci.206

Jiang, Y., Sun, M., Zhao, G., Yuan, C., Xiao, W., Xia, X., Long, X., Wu, F. (2011). Precambrian detrital zircons in the Early Paleozoic Chinese Altai: Their provenance and implications for the crustal growth of central Asia. *Precambrian Res.*, 189, 140–154. doi:10.1016/j.precamres.2011.05.008

Kozakov, I. K., Kozlovsky, A. M., Yarmolyuk, V. V., Kirnozova, T. I., Fugzan, M. M., Oyunchimeg, Ts., Erdenezhargal, Ch. (2019). Geodynamic environments of the origin of poly- and monometamorphic complexes in the southern Altai Metamorphic Belt, Central Asian Orogenic Belt. *Petrology*, 27, 223–242. doi:10.1134/S0869591119030032

Soejono, I., Buriánek, D., Janoušek, V., Svojtka, M., Čáp, P., Erban, V., Ganpurev, N. (2017). A reworked Lake Zone margin: Chronological and geochemical constraints from the Ordovician arc-related basement of the Hovd Zone (western Mongolia). *Lithos*, 294, 112–132. doi:10.1016/j.lithos.2017.08.014

Vorontsov, A., Yarmolyuk, V., Dril, S., Ernst, R., Perfilova, O., Grinev, O., Komaritsyna, T. (2021). Magmatism of the Devonian Altai-Sayan Rift System: Geological and geochemical evidence for diverse plume–lithosphere interactions. *Gondwana Res.,* 89, 193–219. doi: 10.1016/j.gr.2020.09.007

Hoÿm de Marien, L. (de), Štípská, P., Schulmann, K., Kylander-Clark, A., Lexa, O., Jiang, Y., Jeřábek, P., Racek, M., & Buriánek, D. (2026). Permian Syn-Extensional Barrovian Metamorphism in the Envelope of a Migmatite Dome of the Mongolian Altai – Petrostructural and Geochronological Arguments. *Am. J. Sci.*, 326.

Kozakov, I. K., Didenko, A. N., Azimov, P. Ya., Kirnozova, T. I., Sal'nikova, E. B., Anisimova, I. V., & Erdenejargal, Ch. (2011). Geodynamic settings and formation conditions of crystalline complexes in the south Altai and south Gobi metamorphic belts. *Geotectonics*, 45, 174–194.

Ryan, P. D., & Dewey, J. F. (2019). The sources of metamorphic heat during collisional orogeny: The Barrovian enigma. *Can. J. Earth Sci.*, 56, 1309–1317.

Sukhorukov, V. P., Polyansky, O. P., Krylov, A. A., & Zinoviev, S. V. (2016). Reconstruction of the metamorphic P–T path from the garnet zoning in aluminous schists from the Tsogt Block, Mongolian Altai. *Petrology*, 24, 409–432.

Viete, D. R., Richards, S. W., Lister, G. S., Oliver, G. J. H., & Banks, G. J. (2010). Lithospheric-scale extension during Grampian orogenesis in Scotland. *Geol. Soc. Spec. Pub.*, 335, 121–160.

Barrat, J., Bayon, G., Lalonde, S. 2023. Calculation of cerium and lanthanum anomalies in geological and environmental samples. *Chem. Geo.,* 615, https://doi.org/10.1016/j.chemgeo.2022.121202.

Deng, Y., Ren, J., Guo, Q., Cao, J., Wang, H., Liu, C. 2017. Rare earth element geochemistry characteristics of seawater and porewater from deep sea in western Pacific. *Sci. Reports, 7*. https://doi.org/10.1038/s41598-017-16379-1.

Haley, B. A., Klinkhammer, G. P., McManus, J. 2004. Rare earth elements in pore waters of marine sediments. *Geochim. Cosmochim. Acta.,* 68(6), 1265-1279. https://doi.org/10.1016/j.gca.2003.09.012.

Lawrence, M. G., Greig, A., Collerson, K. D., Kamber, B. S. 2006. Rare earth element and Yttrium variability in south east Queensland waterways. *Aquat. Geochem.,* 12, 39-72.

Lumiste, K., Lang, L. Paiste, P., Kirsimäe, K. 2021. Heterogeneous REE + Y distribution in Early Paleozoic shelly phosphorites: Implications for enrichment mechanisms. *Chem. Geo., 586*. https://doi.org/10.1016/j.chemgeo.2021.120590.

Lumiste, K., Mänd, K., Bailey, J., Paiste, P., Lang, L., Lepland, A., Kirsimäe, K. 2019. REE + Y uptake and diagenesis in recent sedimentary apatites. *Chem. Geo.,* 525, 268-281. https://doi.org/10.1016/j.chemgeo.2019.07.034.

Reynard, B., Lécuyer, C., Grandjean, P. 1999. Crystal-chemical controls on rare-earth element concentrations in fossil biogenic apatites and implications for paleoenvironmental reconstructions. *Chem. Geo.,* 155, 233-241. https://doi.org/10.1016/S0009-2541(98)00169-7.

Sholkovitz, E. R., Piepgras, D. J., Jacobsen, S. B. 1989. The pore water chemistry of rare earth elements in Buzzards Bay sediments. *Geochim. Cosmochim. Acta.,* 53, 2847-2856. https://doi.org/10.1016/0016-7037(89)90162-2.

Soares, G. G., Garber, J. M., House, C. H., Reimink, J. R. 2024. Extracting meaningful environmental and age information from a c. 2.4-2.2 Ga peritidal phosphorite: The Turee Creek Group, Western Australia. *Geochem., Geophys., Geosystems.,* 25. https://doi.org/10.1029/2023GC011216.

Amantov, V. A., Volchok, I. I., Luvsandanzan, B., Suetenko, O. D., Borzakovsky, Yu. A. 1970. Geology of the Mongolian People's Republic. Moscow.

Badamgarav, D., et al. 1984. Casarthrid crustaceans of the Noyonsum Formation, Noyon Basin, Mongolia.

Durante, M. V. 1971. Paleobotanical basis for Upper Paleozoic–Permian stratigraphy of southern Mongolia. Candidate dissertation, Geological Institute, USSR Academy of Sciences, Moscow, 32 p.

Durante, M. V. 1976. Paleobotanical basis for Carboniferous–Permian stratigraphy of Mongolia. Nauka, Moscow.

Efremov, I. A., Novozhilov, N. I. 1952. Permian flora of Noyon. *Trudy Paleontologicheskogo Instituta AN SSSR*.

Mossakovsky, A. A., Tumurtogoo, O. 1976. Stratigraphic scheme of the Noyon syncline, southern Mongolia.

Dorjsuren, O., Luvsantseden, U. 2024. Flora and phytostratigraphy from Noyonsum Formation, Late Triassic, Mongolia. *Mongolian Journal of Paleontology*, *5*(1), 5-14.

Barta, D. E., & Norell, M. A. (2021).The osteology of *Haya griva* (Dinosauria: Ornithischia) from the Late Cretaceous of Mongolia. *Bulletin of the American Museum of Natural History*, *445*(1), 1–112. https://doi.org/10.1206/0003-0090.445.1.1

Eberth, D. A., Kobayashi,Y., Lee,Y.-N., Mateus, O.,Therrien, F., Zelenitsky, D. K., & Norell, M. A. (2009). Assignment of *Yamaceratops dorngobiensis* and associated redbeds at Shine Us Khudag (Eastern Gobi, Dorngobi Province, Mongolia) to the redescribed Javkhlant Formation (Upper Cretaceous). *Journal of Vertebrate Paleontology*, *29*(1), 295–302. https://doi.org/10.1671/039.029.0105

Jerzykiewicz,T. (2000). Lithostratigraphy and sedimentary settings of the Cretaceous dinosaur beds of Mongolia. In M. J. Benton, M. A. Shishkin, & D. M. Unwin (Eds.), *The age of dinosaurs in Russia and Mongolia* (pp. 279–296). Cambridge University Press.

Kurzanov, S. M. (1981). An unusual theropod from the Upper Cretaceous of Mongolia. *Joint Soviet-Mongolian Paleontological Expedition*, *15*, 39–49.

Makovicky, P. J., Kilbourne, B. M., Sadleir, R. W., & Norell, M. A. (2011). A new basal ornithopod (Dinosauria, Ornithischia) from the Late Cretaceous of Mongolia. *Journal of Vertebrate Paleontology*, *31*(3), 626–640.

Shuvalov, V. F. (1975). [The stratigraphy of the Mesozoic of Central Mongolia.]. In *Trudy Sovmestnoi Sovetsko-Mongol'skoi Paleontologicheskoi Ekspeditsii* (Vol. 13, pp. 50–112). Leningrad: Nauka.

Watabe, M., & Suzuki, S. (2000). Report on the Japan— Mongolia Joint Paleontological expedition to the Gobidesert, 1996. *Hayashibara Museum of Natural Sciences Research Bulletin*, *1*, 58–68.

Jahn, B.M., 2004. The Central Asian Orogenic Belt and growth of the continental crust in the Phanerozoic. Geol. Soc. Spec. Publ. 226, 73–100. https://doi.org/10.1144/GSL.SP.2004.226.01.05

Jiang, Y.D., Schulmann, K., Sun, M., Weinberg, R.F., Štípská, P., Li, P.F., Zhang, J., Chopin, F., Wang, S., Xia, X.P., Xiao, W.J., 2019. Structural and Geochronological Constraints on Devonian Suprasubduction

Tectonic Switching and Permian Collisional Dynamics in the Chinese Altai, Central Asia. Tectonics 38, 253–280. https://doi.org/10.1029/2018TC005231

Sengor, C., Natalin, B., 1996. Paleotectonics of Asia: Fragments of a syn thesis.

Schulmann, K., Zhang, J., Miao, Y., Guy, A., Soejono, I., Jiang, Y., Sun, M., Shu, T., 2025. Geologically and geophysically constrained kinematic model of the interaction between Mongolian and Kazakhstan collages and the Junggar Block indentation. J. Geol. Soc. London. 182. https://doi.org/10.1144/jgs2024-050

Soejono, I., Peřestý, V., Schulmann, K., Čopjaková, R., Svojtka, M., Štípská, P., Buriánek, D., Janoušek, V., Lexa, O., 2021. Structural, metamorphic and geochronological constraints on Palaeozoic multi-stage geodynamic evolution of the Altai accretionary wedge system (Hovd Zone, western Mongolia). Lithos 396–397. https://doi.org/10.1016/j.lithos.2021.106204

Sukhbaatar, T., Lexa, O., Schulmann, K., Aguilar, C., Štípská, P., Wong, J., Jiang, Y., Míková, J., Zhao, D., 2022. Paleozoic Geodynamics and Architecture of the Southern Part of the Mongolian Altai Zone. Tectonics 41. https://doi.org/10.1029/2022TC007498

Tomurtogoo, O. (2014). Tectonics of Mongolia. Tectonics of northern, central, and eastern Asia, explanatory note to the tectonic map of northern central eastern Asia and adjacent areas at scale, 1: 2500000. (pp. 110–126).

Tomurtogoo, O. (2017). Tectonic map of Mongolia, scale 1:3,000,000 (with brief explanatory legend on the map in Mongolian). Geological Information Centre MRPAM, Ulaanbaatar

Xiao, W., Windley, B.F., Sun, S., Li, J., Huang, B., Han, C., Yuan, C., Sun, M., Chen, H., 2015. A tale of amalgamation of three permo-triassic collage systems in central Asia: Oroclines, sutures, and terminal accretion. Annu. Rev. Earth Planet. Sci. 43, 477–507. https://doi.org/10.1146/annurev-earth-060614-105254

Xiao, W., Windley, B.F., Han, C., Liu, W., Wan, B., Zhang, J., Ao, S., Zhang, Z., Song, D., 2018. Late Paleozoic to early Triassic multiple roll-back and oroclinal bending of the Mongolia collage in Central Asia. Earth-Science Rev. 186, 94–128. https://doi.org/10.1016/j.earscirev.2017.09.020

Windley, B.F., Alexeiev, D., Xiao, W., Kröner, A., Badarch, G., 2007. Tectonic models for accretion of the Central Asian Orogenic Belt. J. Geol. Soc. London. 164, 31–47. https://doi.org/10.1144/0016-76492006-022

Zonenshain L.P., Luvsandanzan, B., Markova, N.G., et al., (1978). Tectonic map of Mongolia, scale 1:500,000 (with brief explanatory legend on the map in Russian).

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