GEODYNAMICS & TECTONOPHYSICS
Published by the Institute of the Earth's Crust, Siberian Branch, Russian Academy of Sciences

PALEOGEODYNAMICS

2023 VOLUME 14 ISSUE 4 ARTICLE 0708

ISSN 2078-502X

DOI: 10.5800/GT-2023-14-4-0708

TECTONOTHERMAL EVOLUTION OF THE ZAGAN METAMORPHIC CORE COMPLEX IN TRANSBAIKALIA AS A RESULT OF THE CRETACEOUS – PALEOCENE MONGOL-OKHOTSK POST-COLLISIONAL OROGEN DESTRUCTION

M.M. Buslov [1✉], **A.V. Travin** [1], **Yu.A. Bishaev** [1], **E.V. Sklyarov** [2]

[1] Sobolev Institute of Geology and Mineralogy, Siberian Branch of the Russian Academy of Sciences, 3 Academician Koptyug Ave, Novosibirsk 630090, Russia

[2] Institute of the Earth's Crust, Siberian Branch of the Russian Academy of Sciences, 128 Lermontov St, Irkutsk 664033, Russia

ABSTRACT. Thermochronological reconstructions of the Zagan metamorphic core complex were carried out using samples from the central part of the core, mylonite zone detachment and lower nappe with U/Pb zircon dating, $^{40}Ar/^{39}Ar$ amphibole and mica dating, and apatite fission-track dating. In the tectonothermal evolution of the metamorphic core, there was distinguished an active phase (tectonic denudation) of the dome structure formation during the Early Cretaceous (131–114 Ma), which continued in the Late Cretaceous – Paleocene (111–54 Ma) in passive phase (erosive denudation). During an active phase, there was initiated a large-amplitude gently dipping normal fault (detachment), which was accompanied by tilting (sliding of rocks along subparallel listric faults). As a result, about 7 km thick rock strata underwent denudation over 17 Ma at a rate of about 0.4 mm/year. In passive phase, about 6 km thick rock strata were eroded over 57 Ma, with a denudation rate of about 0.1 mm/year. Thus, the Zagan metamorphic core complex was tectonically exposed from the mid-crust to depths of about 9 km in the Early Cretaceous as a result of post-collisional collapse of the Mongol-Okhotsk orogen. Further cooling of the rocks in the metamorphic core to depths of about 3 km occurred in the Late Cretaceous – Pliocene as a result of destruction of more than 6 km high mountains.

KEYWORDS: Mongol-Okhotsk orogeny; metamorphic core complex; thermochronology; tectonothermal evolution

FUNDING: The research was supported by RSF (geochronological studies, grant 22-17-00038), state assignment for IEC SB RAS (geological studies) and Government of the Russian Federation (geological studies, grant 075-15-2019-1883).

RESEARCH ARTICLE

Received: February 15, 2023
Revised: April 1, 2023
Accepted: April 11, 2023

Correspondence: Mikhail M. Buslov, buslov@igm.nsc.ru

FOR CITATION: Buslov M.M., Travin A.V., Bishaev Yu.A., Sklyarov E.V., 2023. Tectonothermal Evolution of the Zagan Metamorphic Core Complex in Transbaikalia as a Result of the Cretaceous – Paleocene Mongol-Okhotsk Post-Collisional Orogen Destruction. Geodynamics & Tectonophysics 14 (4), 0708. doi:10.5800/GT-2023-14-4-0708

1. INTRODUCTION

The Zagan metamorphic core complex was the first of its kind to be identified [Sklyarov et al., 1994] in Northern Eurasia and is best known nowadays [Sklyarov et al., 1997; Donskaya et al., 2008, 2013, 2016; Donskaya, Mazukabzov, 2014; Mazukabzov et al., 2006]. The closure of the Mongol-Okhotsk Ocean and a complex collision between the North China continent (Amurian – North China block) and Northern Eurasia [Zonenshain et al., 1990; Zorin, 1999; Tomurtogoo et al., 2005; Donskaya et al., 2013; Shevchenko et al., 2014; Sorokin et al., 2020, 2022] gave rise to the Mongol-Okhotsk orogeny in the Early Mesozoic (Fig. 1). A long-term and complex history of formation of the orogenic belt was accompanied by metamorphic and magmatic processes of different tectonic nature including the formation of metamorphic core complexes.

The metamorphic core complexes are isolated domal or arch-like uplifts of abnormally deformed metamorphic or intrusive complexes, tectonically overlain by non-metamorphosed formations. There are distinguished three bottom-up structural elements: 1) a core composed of granites and granite-gneisses showing partially plastic behavior, 2) a zone of mylonites – tectonically plastic major detachment deformation, 3) tectonic nappe represented by non-metamorphosed formations. The mylonite zone is characterized by various forms of tectonites occurred due to the rocks of the core and nappe. The detailed studies made it possible to substantiate the significance of these specific geological structures as direct indicators of the processes of post-collisional extension when there occurs a rapid tectonic exposure of the mid- and lower crustal metamorphic and magmatic formations [Anderson et al.,1988; Lister, Baldwin, 1993; Sklyarov et al., 1997; Wang et al., 2011, 2012]. During the process of post-collisional extension, there is a considerable decrease in the upper crustal thickness, mainly as a result of tectonic denudation caused by two interrelated processes: upper megaplate creeping along the large-amplitude gently dipping normal fault (detachment) zone and tilting. Tilting is the process of formation of a series of subparallel listric normal faults along which the tectonic blocks were flattened out in a domino effect [Wernicke, 1981].

The metamorphic core complexes of Transbaikalia [Sklyarov et al., 1994, 1997; Mazukabzov et al., 2006; Donskaya et al., 2008, 2013, 2016; Donskaya, Mazukabzov, 2014] are located in a southeastward direction, in the immediate vicinity of the world's largest Angara-Vitim batholith. They are generally NE-trending, 20–30 km wide, and extending for 50–150 km along the strike (Fig. 2). The cores are usually composed of the Late Paleozoic granites and granite-gneisses. The mylonite zone is characterized by various forms of tectonites occurred primarily due to the rocks in the core, less often to those in the lower nappe. Among the nappes are the Upper Paleozoic and Mesozoic volcanogenic-sedimentary rocks. They are non-metamorphosed and prone to brittle deformations. The metamorphic core complexes of Transbaikalia are characterized by the same-type synmetamorphic structurtal parageneses: gently dipping schistosity, micro- and macrostructures (folds, linearity, boudinage, pressure shadows, C–S structures, kinkbands). The kinematic analysis shows that their mechanism is a simple shear along the deep-penetrating fault zones gently dipping to the southeast. The tectonic transport of material occurred in the same direction. The

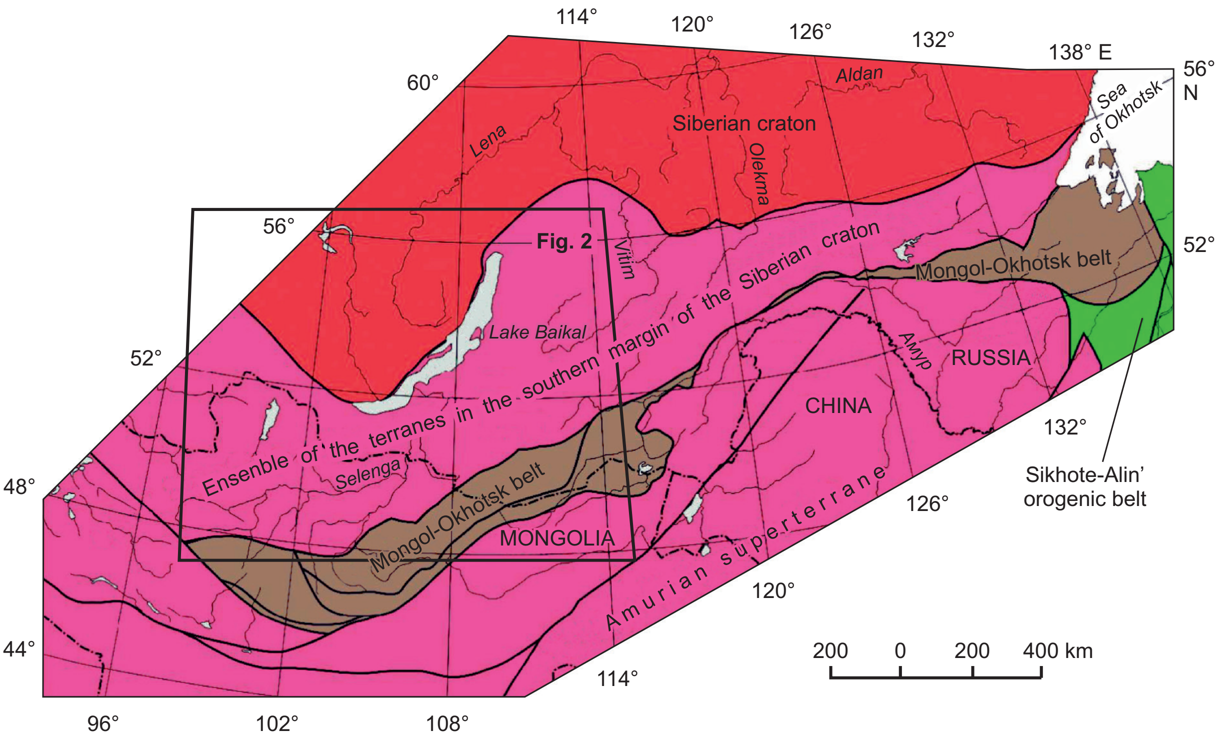

Fig. 1. The Mongol-Okhotsk Belt and major tectonic units of East Asia after [Parfenov et al., 2001; Sorokin et al., 2022].

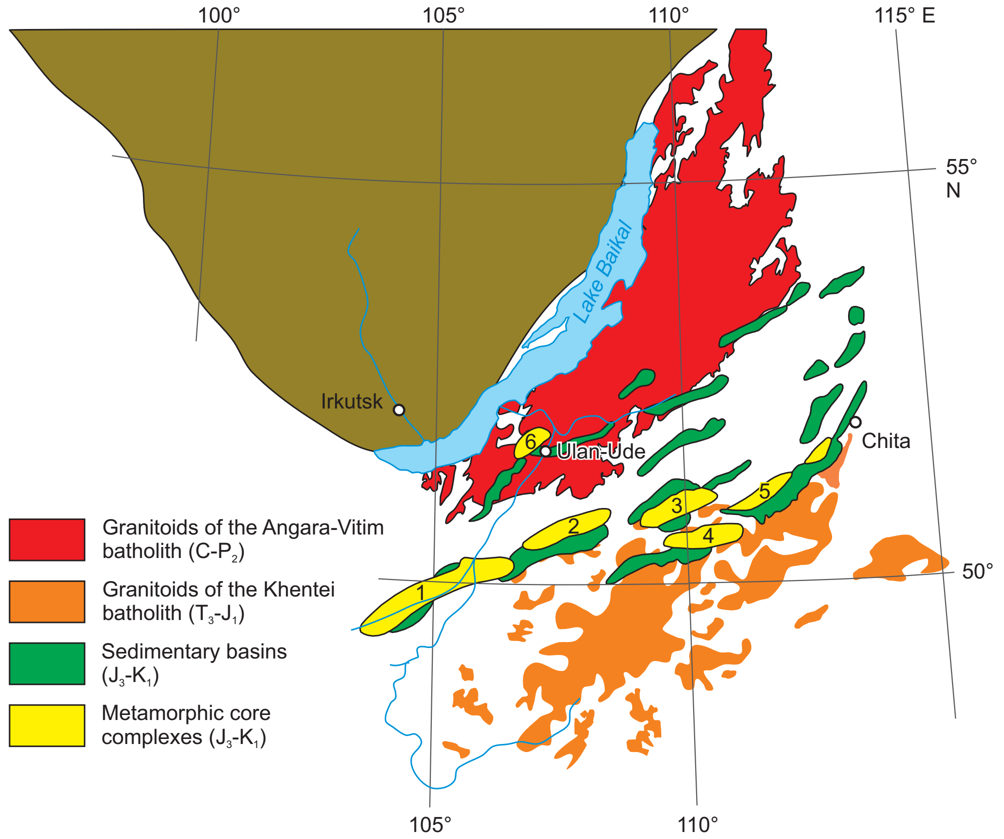

Fig. 2. Scheme of location of metamorphic core complexes and the Angara-Vitim batholith in the structure of Transbaikalia (according to [Yarmolyuk et al., 2002; Kuzmin et al., 2010; Tsygankov et al., 2017; Sklyarov et al., 1997]). The numbers on the scheme indicate metamorphic core complexes: 1 – Butuliyn-Nur, 2 – Zagan, 3 – Tsagankhuntei, 4 – Malkhan, 5 – Yablonovyi, 6 – Selenga.

extensional deformation was NW–SE trending. Such movements gave rise to the formation of listric normal faults and rift basins bordering the metamorphic core complexes. The most intensive period of tectonic exposure of metamorphic cores is determined as 112–123 Ma, and the period of manifestation of metamorphic processes – as 140–130 Ma. The rocks in the deep-seated fault zone were transformed under conditions of greenschist and epidote-amphibole facies metamorphism (T=350–640 °C and P=3.2–4.6 KBar).

The structural-geological, petrological and isotopic data [Sklyarov et al., 1994, 1997; Donskaya et al., 2008, 2013, 2016; Donskaya, Mazukabzov, 2014; Mazukabzov et al., 2006] show that most of the metamorphic rocks of Transbaikalia are of Late Mesozoic age. It is implied that they were formed in an extensional regime due to collapse of the Late Mesozoic orogeny which occurred during the Early Mesozoic closure of the oceanic basin of the same name and complex collision between the North China continent (Amurian – North China block) and Northern Eurasia [Zonenshain et al., 1990; Zorin, 1999; Tomurtogoo et al., 2005; Donskaya et al., 2013; Shevchenko et al., 2014; Sorokin et al., 2020]. It is believed [Sklyarov et al., 1997; Donskaya et al., 2008, 2013, 2016; Donskaya, Mazukabzov, 2014; Mazukabzov et al., 2006] that thickening of the continental crust due to the nappe formation caused an intensification of heat transfer and an increase in the lower-crustal plasticity. This predetermined the unstable orogeny and orogenic spreading which gave rise to the occurrence of regional extension and lower- and mid-crustal detachment faulting. Crustal thinning was accompanied by isostatic uplift during late-stage extension which provided exposures of the mid-crustal structural-material complexes and was favorable to the formation of the metamorphic core complexes.

The main objective of the study is to substantiate the tectonothermal evolution of the Zagan metamorphic core using new U-Pb zircon ages, Ar-Ar dating of amphiboles and micas, and apatite fission-track dating, and to estimate tectonic and erosional denudation thicknesses for the Cretaceous – Paleogene Mongol-Okhotsk orogeny.

2. GEOLOGICAL STRUCTURE OF THE ZAGAN METAMORPHIC CORE

The Zagan metamorphic core complex comprises the northeast-trending Zagan Range surrounded by the Late Mesozoic volcanogenic-sedimentary formations of the Khilok basin on the south and the Tugnuy basin on the north (Fig. 3). Its structure consists of a core, composed mostly of numerous massive locally foliated granitoids, a mylonite zone bordering the core and comprising an antiform structure, and a nappe made up of the Late Paleozoic-Mesozoic volcanogenic-sedimentary rocks [Mazukabzov et al., 2011]. The core is composed of syenites and granosyenites,

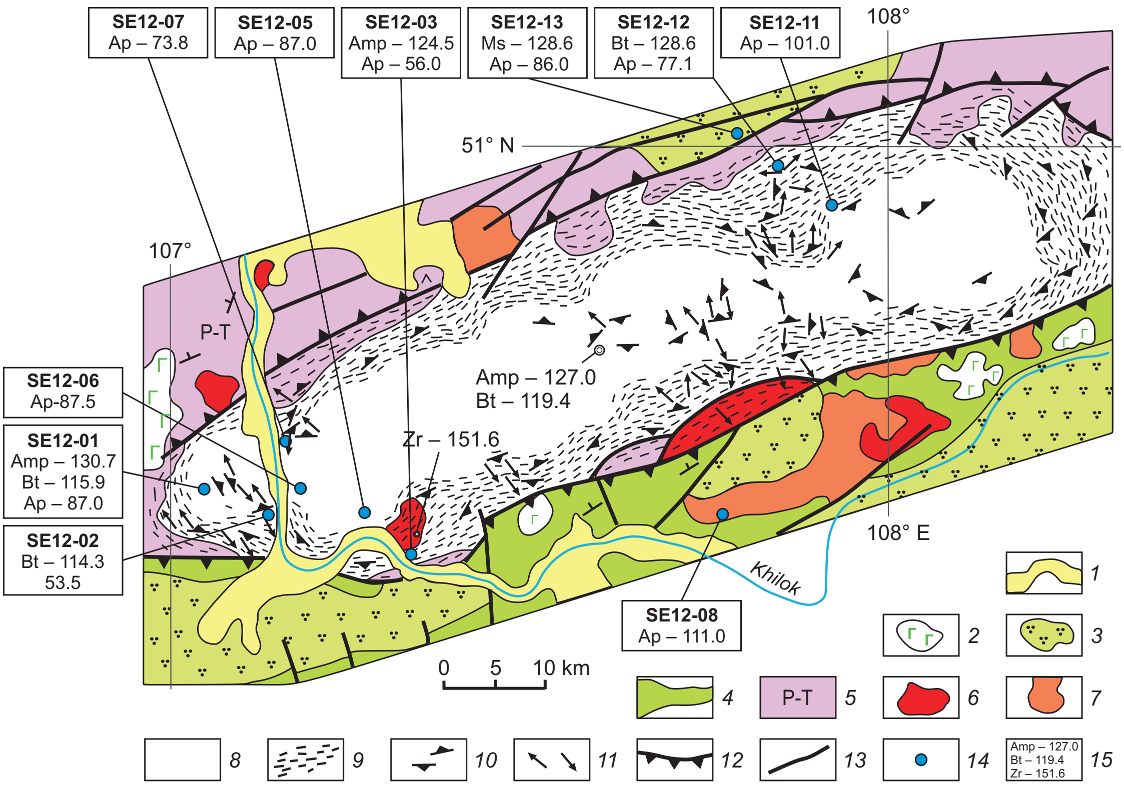

Fig. 3. Geological scheme of the Zagan metamorphic core complexes (after [Mazukabzov et al., 2011]).
1 – Quaternary sediments; *2* – Cenozoic basalts; *3* – Early Cretaceous sediments; *4* – Early Cretaceous volcanogenic-sedimentary formations; *5* – Permian-Triassic volcanogenic-sedimentary formations; *6* – Late Jurassic granosyenites, including those from the Margituy massif with the age of 151 Ma [Donskaya et al., 2016]; *7* – Late Paleozoic granites; *8* – core granitoids; *9* – mylonite zone; *10* – foliation; *11* – linearity; *12* – detachment; *13* – subvertical faults; *14* – sampling sites for geochronological dating; *15* – U-Pb zircon (Zr) ages, Ar-Ar amphibole (Amp), biotite (Bt) and muscovite (Ms) ages, apatite (Ap) fission-track ages. Names of minerals are abbreviated after [Warr, 2021].

gneiss-granites, medium-grained granites, and granodiorites. Gneiss-granites and foliated granodiorites are confined to the marginal pars of the Zagan Uplift and gradually change to unaltered granitoid rocks. Dark-colored minerals therein acquire a mutually parallel position and provide linear-planar rock texture. Zircon U-Pb age of granitoids from the central part of the core is 260 Ma [Mazukabzov et al., 2011]. They are intruded by the 153 Ma old granites from the Margituy massif [Donskaya et al., 2008], syntectonic in accordance with their development time and reflecting initial processes of the metamorphic core complex formation.

The mylonites comprise a flat-lying zone of dynamometamorphic rocks developed both along the granitoids in the core and the Late Paleozoic-Mesozoic volcanogenic-sedimentary formations of the nappe. The apparent thickness of the mylonite zone is estimated at 2.0–2.5 km. Massive granitoids in the core gradually change to amphibole-biotite and biotite gneisses of the mylonite zone. Among those are amphibolites whose thickness can reach one hundred meters. Tectonites derived from the Early Triassic conglomerates form the northern part of Zagan metamorphic core. The mylonite zone is characterized by the upsection transition from epidote-amphibolite to greenschist facies metamorphism. Based on the degree of initial rock transformation, there may be distinguished protomylonites, mylonites and mylonitic schists, blastomylonites and pseudotachylites [Sklyarov et al., 1997]. All types of mylonites are tabular-shaped and concordant to each other.

Ar-Ar dating of amphibole and biotite from amphibolite schists occurring among mylonitic gneisses allowed us to determine the time intervals for the brittle-ductile transition in rocks at the upper-crustal level. These intervals are 127±2 Ma for syntectonic hornblende and 119–112 Ma for syntectonic biotite. The dates obtained led to the conclusion that tectonic development of the Zagan metamorphic core complex occurred in Late Jurassic – Early Cretaceous and lasted for 45–50 Ma [Sklyarov et al., 1997].

3. RESULTS

Thermochronological reconstructions involve a complex of geochronological methods characterized by different temperatures of the closure of mineral isotopic systems: from zircon U-Pb dating (temperature of the closure T_c ~900 °C) and ^{40}Ar/^{39}Ar dating of amphibole (T_c ~550 °C), biotite, muscovite (T_c ~320 °C), feldspar/plagioclase (T_c ~300 °C) to fission-track dating of apatite (T_c ~110 °C) [Hodges, 2004]. The comparison between the ages obtained for mineral isotopic systems and temperatures obtained for their closure allows the sequential estimation of the occurrence depths of the rocks (considering the average temperature gradient of 25–30 °/km) for different time intervals starting from their formation and ending with their surface exposure in result of tectonic events. Such multisystem approach was used by us [Travin et al., 2022] to study tectonothermal evolution of the Late Paleozoic granitoids of the Angara-Vitim batholith located in the central Transbaikalia near the Zagan metamorphic core (see Fig. 2). It was concluded that during the Mongol-Okhotsk orogeny (170–140 Ma ago), there occurred the rock uplift of the Angara-Vitim batholith from 10–7 to 4–3 km depths, which may be due to intensive orogeny in Transbaikalia and denudation of about 6–4 km thick earth's crust.

Thermochronological reconstructions of the Zagan metamorphic core were performed based on the samples from the central part of the core, mylonite zone and lower nappe (App. 1, Table 1.1) using zircon U-Pb dating, $^{40}Ar/^{39}Ar$ dating of amphibole and micas, and fission-track dating of apatite. Zircon U-Pb and apatite fission-track ages were obtained by LA-ICP-MS at the Kazan Federal University; $^{40}Ar/^{39}Ar$ mineral ages (Fig. 4) were obtained by full-scale plateau-based step heating at the Institute of Geology and Mineralogy SB RAS [Travin, 2016], and apatite fission-track lengths were also measured therein.

Table 1.1 and a thermochronologicasl diagram (Fig. 5) present the results for new and already published datasets that include isotopic and fission-track ages of minerals from the Zagan metamorphic core complex rocks. Zircon U-Pb ages reflecting the granite melt consolidation time are distributed over the interval 253 to 250 Ma [Mazukabzov et al., 2011; Bishaev et al., 2022]. This interval corresponds to the formation time of granitoids of the Khagai batholith (255±10 Ma), located south of the central Mongolia [Yarmolyuk et al., 2002; Kuzmin et al., 2010].

$^{40}Ar/^{39}Ar$ ages obtained for hornblende and biotite (App. 1, Table 1.1; see Fig. 4) from the mylonite zone fall within the ranges of 131 to 125 and of 120 to 114 Ma, respectively. Considering the age of the closure of amphibole and biotite isotopic systems (see Fig. 4) characterizing the mylonite zone, the Late Permian – Early Triassic granitoid deformation may have occurred in temperature interval T_c ~550 °C – T_c ~320 °C, which correspond to depths of 17 and 10 km, respectively, with the average temperature gradient assumed to be 25–30 °/km. The data obtained for thermal history of minerals from the mylonite zone testify to the fact that the magmatic and metamorphic complexes, composing the Zagan metamorphic core complex in the Early Cretaceous (131–114 Ma), experienced a rapid uplift which was accompanied by the denudation of the overlying rocks with a thickness of about 7 km. The denudation rate was about 0.4 mm/yr. The denudation thickness is estimated based on the 230 °C difference between the depth temperatures at which there occurs the closure of the hornblende and biotite isotopic systems.

Apatite fission-track dating shows that cooling of the rocks of the Zagan metamorphic core occurred in the period from 111 to 54 Ma (Late Cretaceous – Paleocene) (Fig. 5). In that period of time, different parts of the core crossed

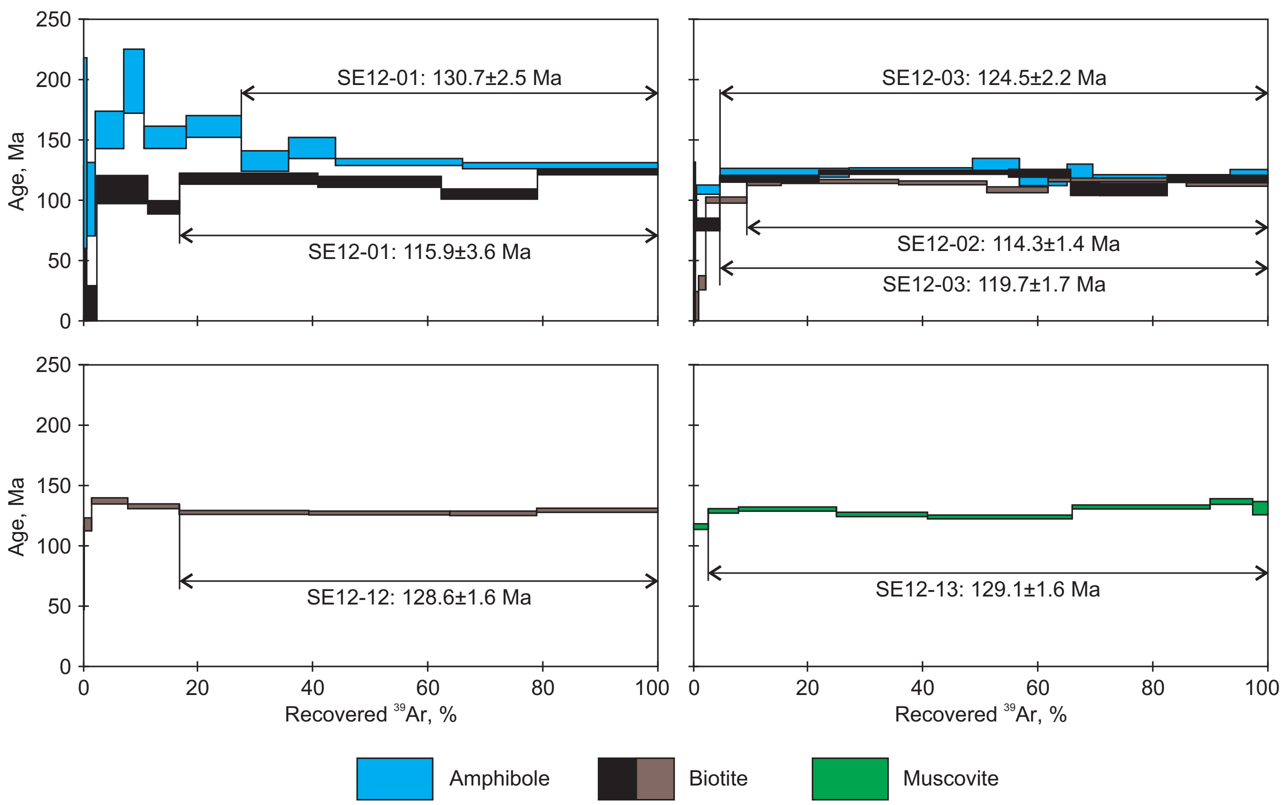

Fig. 4. Results of Ar-Ar dating of minerals from the rocks of the mylonite zone of the Zagan metamorphic core complexes. See Fig. 2 and App. 1, Table 1.1 for locations.

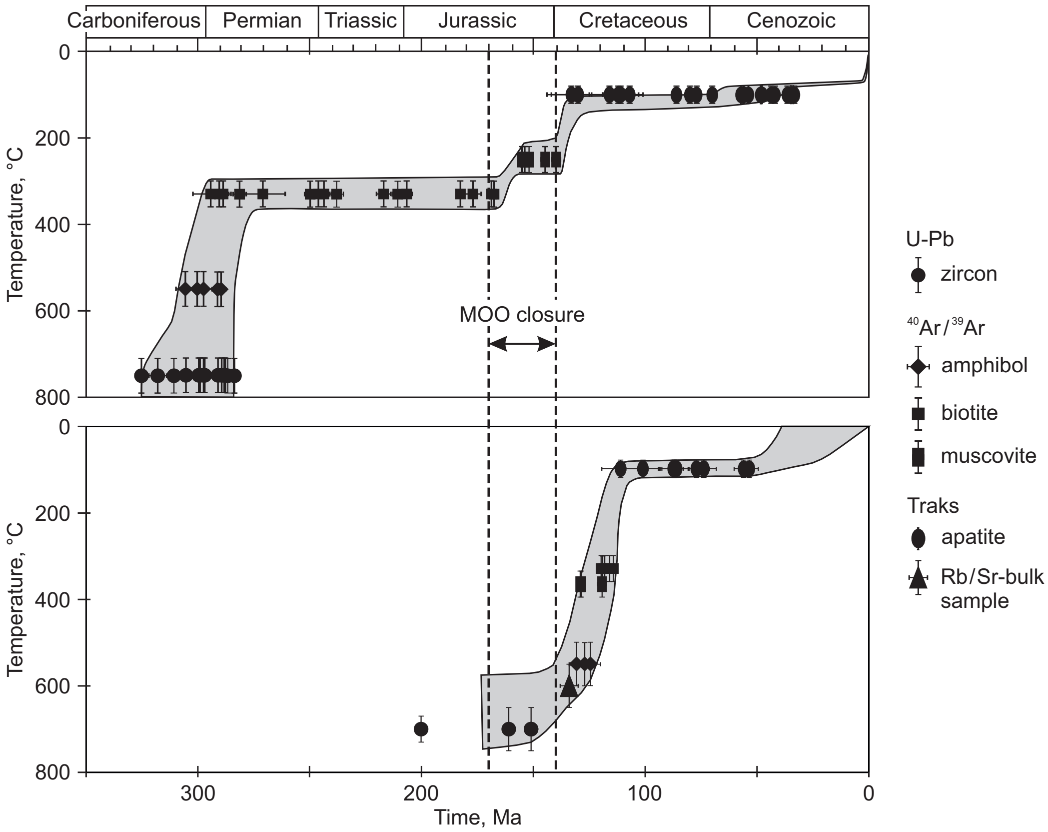

Fig. 5. Thermochronological diagram of the evolution of rocks from the Angara-Vitim batholith (upper row) [Travin et al., 2022] and the Zagan metamorphic core complexes (lower row). See App. 1, Table 1.1 for the initial complexes data.

the T_c ~110 °C isograd (depth about 3 km) from which the apatite fission tracks start to form (track age). The Late Cretaceous – Paleocene denudation thickness is determined based on the difference between the closure of biotite (T_c ~320 °C) and apatite (T_c ~110 °C) isotopic systems which is 210 °C. The denudation thickness is estimated at 6 km, the denudation rate – at about 0.1 mm/yr.

The time period of the long-term quiescence (Eocene – Miocene) changed to the Pliocene – Quaternary reactivation of Transbaikalia due to the distant impact of the Indo-Eurasian collision [Dobretsov et al., 1996; Jolivet et al., 2009; De Grave et al., 2007; Buslov, 2012], as a result of which the studied rocks of the Zagan metamorphic core became exposed. The denudation thickness was about 3 km.

4. DISCUSSION

The closure of the Mongol-Okhotsk Ocean and complex collision between the North China continent (Amurian – north China block) and Northern Eurasia gave rise to the development of the Mongol-Okhotsk orogeny. Thickening of the continental crust, associated with the nappe formation, caused an intensification of heat transfer and an increase in the lower-crustal plasticity. This predetermined the unstable orogeny and orogenic collapse which led to the initiation of detachment fault – a large-amplitude normal fault dipping gently southeastwards (in terms of modern coordinates) (Fig. 6, a). The start time for its formation can be determined from the age of alkaline granites of the Margituy complex in the zone of blastomylonites showing the crystallization behavior in terms of active tectogenesis conditions [Donskaya et al., 2008]. The age of granites is 153 Ma.

In the Early Cretaceous, there was a significant decrease in the upper crustal thickness resulted from tectonic denudation which, in accordance with the Wernicke model [Wernicke, 1981], was caused by two interrelated processes (Fig. 6, b): upper megaplate creeping southeastward (in terms of modern coordinates) and formation of a series of listric normal faults (tilting). The occurrence time of these events corresponds to the interval from 131 to 114 Ma over which about 7 km thick overlying rocks were denudated. The tectonic denudation rate is estimated at 0.4 mm/yr.

The next interval from 111 to 54 Ma is characterized by slowing-down denudation rate of the overlying rocks which may be due to slowing-down or cessation of the extension processes and an uplift of the magmatic and metamorphic complexes caused by isostatic floating of relatively light granite masses and erosional denudation of the upper crust. The erosional denudation rate at that period is estimated at 0.1 mm/yr.

The comparison between the denudation rates shows that tectonic denudation at early stages of orogenic collapse was four times more effective than that responsible for removal of overlying complexes at the late stage of the system development.

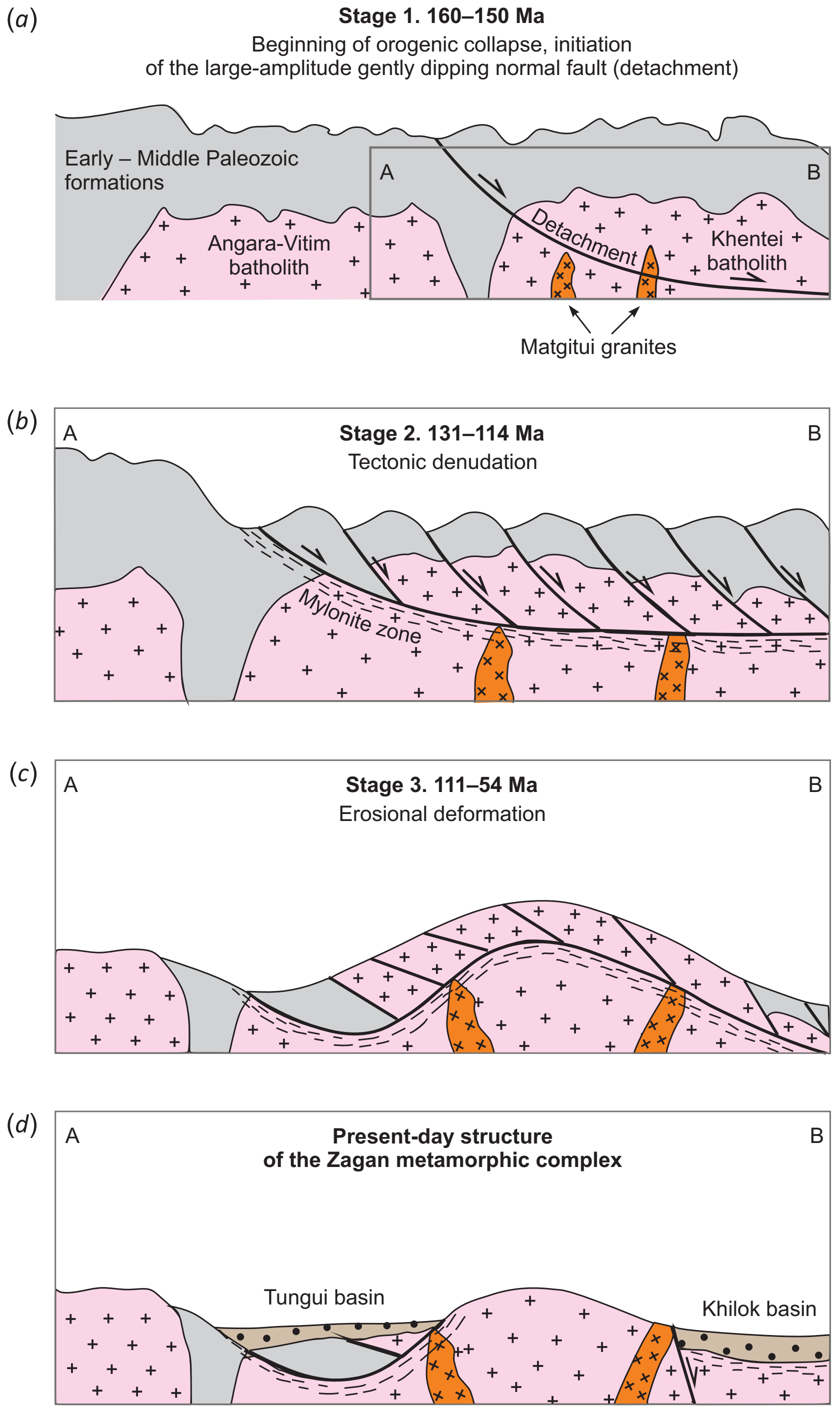

Fig. 6. Schematic model of the formation of the Zagan metamorphic core complexes (see text for explanations). The arrows show the direction of displacement along the faults.

It was not until the last stages of its evolution that the Zagan metamorphic core complex took a dome-like shape due to floating of a relatively light granitoid substrate (Fig. 6, c). An early-stage existence of a regional gently dipping normal fault (detachment) is evidenced by up to 2.0–2.5 km thick zones of blastomylonites on the northern and southern flanks of the Zagan metamorphic core complex and the same direction of displacement (upward southeast) in the northern and southern zones of blastomylonites [Sklyarov et al., 1994, 1997].

5. CONCLUSION

The data obtained for the tectonothermal evolution of the Zagan metamorphic core lead to the following conclusions:

1. According to $^{40}Ar/^{39}Ar$ dating of amphiboles and micas from the mylonite zone, the time of an active development of the Zagan metamorphic core complex corresponds to the Early Cretaceous (131–114 Ma) with a duration of 17 Ma. Tectonic exposure of the core from the mid-crust levels to depths of about 9 km occurred at a high rate of

tectonic erosion (about 0.4 mm/Ma) as a result of post-collisional extension of the Mongol-Okhotsk orogen.

2. Apatite fission-track dating shows that further cooling of the rocks in the Zagan metamorphic core to T_c ~110 °C (from a depth of about 3 km) occurred in the Late Cretaceous – Paleocene (111–54 Ma) with a duration of 57 Ma. The erosional denudation rate was about 0.1 mm/yr. The process was caused by destruction of the mountain over 6 km high.

3. The presented results show that the tectonic denudation rate was four times higher than the erosional denudation rate during the mountain destruction.

6. ACKNOWLEDGEMENTS

The authors express their sincere gratitude to the reviewers, A.A. Sorokin, Corr. Mem., and A.A. Tsygankov, Dr. Sci. (Geol.-Min.), whose comments and suggestions have been very useful for improving the research paper.

7. CONTRIBUTION OF THE AUTHORS

All authors made an equivalent contribution to this article, read and approved the final manuscript.

8. DISCLOSURE

The authors declare that they have no conflicts of interest relevant to this manuscript.

9. REFERENCES

Anderson J.L., Barth A.P., Young E.D., 1998. Mid-Crustal Cretaceous Roots of Cordilleran Metamorphic Core Complexes. Geology 16 (4), 366–369. https://doi.org/10.1130/0091-7613(1988)016<0366:MCCROC>2.3.CO;2.

Bishaev Yu.A., Buslov M.M., Travin A.V., 2022. Tectonothermal Evolution of Western Transbaikalia in the Late Cretaceous – Cenozoic Based on Apatite Fission-Track Dating. In: Geodynamic Evolution of the Lithosphere of the Central Asian Mobile Belt (from Ocean to Continent). Proceedings of Scientific Meeting (October 18–21, 2022). Iss. 20. IEC SB RAS, Irkutsk, p. 27–28 (in Russian) [Бишаев Ю.А., Буслов М.М., Травин А.В. Тектонотермальная эволюция Западного Прибайкалья в позднем мелу – кайнозое по данным трекового датирования апатита // Геодинамическая эволюция литосферы Центрально-Азиатского подвижного пояса (от океана к континенту): Материалы научного совещания (18–21 октября 2022 г.). Иркутск: ИЗК СО РАН, 2022. Вып. 20. С. 27–28].

Buslov M.M., 2012. Geodynamic Nature of the Baikal Rift Zone and Its Sedimentary Filling in the Cretaceous–Cenozoic: The Effect of the Far-Range Impact of the Mongolo-Okhotsk and Indo-Eurasian Collisions. Russian Geology and Geophysics 53 (9), 955–962. https://doi.org/10.1016/j.rgg.2012.07.010.

De Grave J., Buslov M.M., Van Den Haute P., 2007. Distant Effects of India-Eurasia Convergence and Mesozoic Intracontinental Deformation in Central Asia: Constraints from Apatite Fission-Track Thermochronology. Journal of Asian Earth Sciences 29 (2–3), 188–204. http://doi.org/10.1016/j.jseaes.2006.03.001.

Dobretsov N.L., Buslov M.M., Delvaux D., Berzin N.A., Ermikov V.D., 1996. Meso- and Cenozoic Tectonics of the Central Asian Mountain Belt: Effects of Lithospheric Plate Interaction and Mantle Plume. International Geology Review 38 (5), 430–466. https://doi.org/10.1080/00206819709465345.

Donskaya T.V., Gladkochub D.P., Mazukabzov A.M., Ivanov A.V., 2013. Late Paleozoic – Mesozoic Subduction-Related Magmatism at the Southern Margin of the Siberian Continent and the 150 Million-Year History of the Mongol-Okhotsk Ocean. Journal of Asian Earth Sciences 62, 79–97. https://doi.org/10.1016/j.jseaes.2012.07.023.

Donskaya T.V., Gladkochub D.P., Mazukabzov A.M., Wang T., Guo L., Rodionov N.V., Demonterova E.I., 2016. Mesozoic Granitoids in the Structure of the Bezymyannyi Metamorphic-Core Complex (Western Transbaikalia). Russian Geology and Geophysics 57 (11), 1591–1605. https://doi.org/10.1016/j.rgg.2016.10.005.

Donskaya T.V., Mazukabzov A.M., 2014. The Geochemistry and Ages of Rocks in the Footwall of the Butuliyn-Nur and Zagan Metamorphic Core Complexes (North Mongolia – Western Transbaikalia). Geodynamics & Tectonophysics 5 (3), 683–701 (in Russian) [Донская Т.В., Мазукабзов А.М. Геохимия и возраст пород нижних пластин Бутулийн-Нурского и Заганского комплексов метаморфических ядер (Северная Монголия – Западное Забайкалье) // Геодинамика и тектонофизика. 2014. Т. 5. № 3. С. 683–701]. https://doi.org/10.5800/GT-2014-5-3-0149.

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., Hegner E., 2008. Age and Evolution of Late Mesozoic Metamorphic Core Complexes in Southern Siberia and Northern Mongolia. Journal of the Geological Society 165 (1), 405–421. http://doi.org/10.1144/0016-76492006-162.

Hodges K.V., 2004. Geochronology and Thermochronology in Orogenic Systems. In: H.D. Holland, K.K. Turekian (Eds), Treatise on Geochemistry. Vol. 3. Elsevier, p. 263–292. https://doi.org/10.1016/B0-08-043751-6/03024-3.

Jolivet M., De Boisgrollier T., Petit C., Fournier M., Sankov V.A., Ringenbach J.-C., Byzov L., Miroshnichenko A.I., Kovalenko S.N., Anisimova S.V., 2009. How Old Is the Baikal Rift Zone? Insight from Apatite Fission Track Thermochronology. Tectonics 28 (3). http://doi.org/10.1029/2008TC002404.

Kuzmin M.I., Yarmolyuk V.V., Kravchinsky V.A., 2010. Phanerozoic Hot Spot Traces and Paleogeographic Reconstructions of the Siberian Continent Based on Interaction with the African Large Low Shear Velocity Province. Earth-Science Reviews 102 (1–2), 29–59. https://doi.org/10.1016/j.earscirev.2010.06.004.

Lister G.S., Baldwin S.L., 1993. Plutonism and Origin of Metamorphic Core Complexes. Geology 21 (7), 607–610. https://doi.org/10.1130/0091-7613(1993)021<0607:PATOOM>2.3.CO;2.

Mazukabzov A.M., Donskaya T.V., Gladkochub D.P., Sklyarov E.V., Ponomarchuk V.A., Sal'nikova E.B., 2006. Structure and Age of the Metamorphic Core Complex of the Burgutui Ridge (Southwestern Transbaikal Region). Doklady Earth

Sciences 407, 179–183. https://doi.org/10.1134/S1028334X06020048.

Mazukabzov A.M., Sklyarov E.V., Donskaya T.V., Gladkochub D.P., Fedorovsky V.S., 2011. Metamorphic Core Complex of the Transbaikalia: Review. Geodynamics & Tectonophysics 2 (2), 95–125 (in Russian) [Мазукабзов А.М., Скляров Е.В., Донская Т.В., Гладкочуб Д.П., Федоровский В.С. Комплексы метаморфических ядер Забайкалья: обзор // Геодинамика и тектонофизика. 2011. Т. 2. № 2. С. 95–125]. https://doi.org/10.5800/GT-2011-2-2-0036.

Parfenov L.M., Popeko L.I., Tomurtogoo O., 2001. Problems of Tectonics of the Mongol-Okhotsk Orogenic Belt. Geology of the Pacific Ocean 16 (5), 797–830.

Shevchenko B.F., Popeko L.I., Didenko A.N., 2014. Tectonics and Evolution of the Lithosphere of the Eastern Fragment of the Mongol-Okhotsk Orogenic Belt. Geodynamics & Tectonophysics 5 (3), 667–682 (in Russian) [Шевченко Б.Ф., Попеко Л.И., Диденко А.Н. Тектоника и эволюция литосферы восточной части Монголо-Охотского орогенного пояса // Геодинамика и тектонофизика. 2014. Т. 5. № 3. С. 667–682]. https://doi.org/10.5800/GT-2014-5-3-0148.

Sklyarov E.V., Mazukabzov A.M., Donskaya T.V., Doronina N.A., Shafeev A.A., 1994. Complex of the Metamorphic Core of the Zagan Ridge (Transbaikalia). Doklady Earth Science 339 (1), 83–86 (in Russian) [Скляров Е.В., Мазукабзов А.М., Донская Т.В., Доронина Н.А., Шафеев А.А. Комплекс метаморфического ядра Заганского хребта (Забайкалье) // Доклады АН. 1994. Т. 339. № 1. С. 83–86].

Sklyarov E.V., Mazukabzov A.M., Melnikov A.I., 1997. Metamorphic Core Complexes of the Cordilleran Type. Publishing House of SPC UIGGM SB RAS, Novosibirsk, 182 p. (in Russian) [Скляров Е.В., Мазукабзов А.М., Мельников А.И. Комплексы метаморфических ядер кордильерского типа. Новосибирск: Изд-во НИЦ ОИГГМ СО РАН, 1997. 182 с.].

Sorokin A.A., Zaika V.A., Kadashnikova A.Yu., Ponomarchuk V.A., Travin A.V., Ponomarchuk V.A., Buchko I.V., 2022. Mesozoic Thermal Events and Related Gold Mineralization in the Eastern Mongol-Okhotsk Orogenic Belt: Constraints from Regional Geology and $^{40}Ar/^{39}Ar$ Dating. International Geology Review 65 (9), 1476–1499. https://doi.org/10.1080/00206814.2022.2092781.

Sorokin A.A., Zaika V.A., Kovach V.P., Kotov A.B., Xu W., Yang H., 2020. Timing of Closure of the Eastern Mongol-Okhotsk Ocean: Constraints from U-Pb and Hf Isotopic Data of Detrital Zircons from Metasediments along the Dzhagdy Transect. Gondwana Research 81, 58–78. https://doi.org/10.1016/j.gr.2019.11.009.

Tomurtogoo O., Windley B.F., Kröner A., Badarch G., Liu D.Y., 2005. Zircon Age and Occurrence of the Adaatsag Ophiolite and Muron Shear Zone, Central Mongolia: Constraints on the Evolution of the Mongol-Okhotsk Ocean, Suture and Orogen. Journal of the Geological Society 162, 125–134. https://doi.org/10.1144/0016-764903-146.

Travin A.V., 2016. Thermochronology of Early Paleozoic Collisional and Subduction-Collisional Structures of Central Asia. Russian Geology and Geophysics 57 (3), 434–450. https://doi.org/10.1016/j.rgg.2016.03.006.

Travin A.V., Buslov M.M., Bishaev Yu.A., Tsygankov A.A., 2022. Thermochronology of the Angara-Vitim Granitoid Batholith as an Evolution Record of the Mongol-Okhotsk Orogen. Doklady Earth Sciences 507 (S3), S396–S399. https://doi.org/10.1134/S1028334X22601687.

Tsygankov A.A., Burmakina G.N., Khubanov V.B., Buyantuev M.D., 2017. Geodynamics of Late Paleozoic Batholith Forming Processes in Western Transbaikalia. Petrology 25, 396–418. https://doi.org/10.1134/S0869591117030043.

Wang T., Guo L., Zheng Y., Donskaya T., Gladkochub D., Zeng L., Li J., Wang Y., Mazukabzov A., 2012. Timing and Processes of Late Mesozoic Mid-Lower-Crustal Extension in Continental NE Asia and Implications for the Tectonic Setting of the Destruction of the North China Craton: Mainly Constrained by Zircon U-Pb Ages from Metamorphic Core Complexes. Lithos 154, 315–345. https://doi.org/10.1016/j.lithos.2012.07.020.

Wang T., Zheng Y., Zhang J., Zeng L., Donskaya T., Guo L., Li J., 2011. Pattern and Kinematic Polarity of Late Mesozoic Extension in Continental NE Asia: Perspectives from Metamorphic Core Complexes. Tectonics 30 (6), TC6007. https://doi.org/10.1029/2011TC002896.

Warr L.N., 2021. IMA–CNMNC Approved Mineral Symbols. Mineralogical Magazine 85 (3), 291–320. https://doi.org/10.1180/mgm.2021.43.

Wernicke B., 1981. Low-Angle Normal Faults in the Basin and Range Province: Nappe Tectonics in Extended Orogen. Nature 291, 645–648. https://doi.org/10.1038/291645a0.

Yarmolyuk V.V., Kovalenko V.I., Sal'nikova E.B., Budnikov S.V., Kovach V.P., Kotov A.B., Ponomarchuk V.A., 2002. Tectonomagmatic Zoning, Magma Sources, and Geodynamics of the Early Mesozoic Mongolia–Transbaikal Province. Geotectonics 36 (4), 293–311.

Zonenshain L.P., Kuzmin M.I., Natapov L.M., 1990. Tectonics of Lithospheric Plates of the USSR. Book 1. Nedra, Moscow, 328 p. (in Russian) [Зоненшайн Л.П., Кузьмин М.И., Натапов Л.М. Тектоника литосферных плит территории СССР. Кн. 1. М.: Недра, 1990. 328 с.].

Zorin Yu.A., 1999. Geodynamics of the Western Part of the Mongolia–Okhotsk Collisional Belt, Trans-Baikal Region (Russia) and Mongolia. Tectonophysics 306 (1), 33–56. https://doi.org/10.1016/S0040-1951(99)00042-6.

APPENDIX 1

Table 1.1. Results of U/Pb zircon dating, Ar/Ar amphibole, biotite and muscovite dating, and AFT dating of apatite from the Zagan metamorphic core complex. Core: SE12-05-12; mylonite zone: SE12-01-03; nappe: SE12-13

Number	Coordinates	Height, m	Rock	U/Pb, Ma	Ar/Ar Amp, Ma	Ar/Ar Bt, Ma	Ar/Ar Mu, Ma	AFT, Ma
SE12-01	50°41.105' 107°6.063'	920	gneiss	–	130.7±2.5	115.9±3.6	–	87.0
SE12-02	50°40.308' 107°6.995'	912	gneiss	–	–	114.3±1.4	–	53.5
SE12-03	50°38.16' 107°18.591'	615	amphibole and biotite schist	–	122.0±1.8	119.7±1.7	–	56.0
SE12-05	50°71.181' 107°15.031'	862	diorite	253	–	–	–	87.0
SE12-06	50°42.467' 107°8.433'	615	diorite	–	–	–	–	87.5
SE12-07	50°44.45' 107°7.866'	615	granosyenite	253	–	–	–	73.8
SE12-08	50°40.909' 107°47.677'	614	granosyenite	290	–	–	–	111.0
SE12-11	50°56.116' 107°55.665'	1044	granite	200, 250, 290	–	–	–	101.0
SE12-12	51°0.522' 107°49.714'	614	granosyenite	–	–	128.6±1.6	–	77.1
SE12-13	51°0.755' 107°47.932'	615	metacon-glomerate	–	–	–	129.1±6.0	86.0