ISSN 1028-334X, Doklady Earth Sciences, 2010, Vol. 434, Part 1, pp. 1147–1151. © Pleiades Publishing, Ltd., 2010.
Original Russian Text © M.M. Buslov, F.I. Zhimulev, A.V. Travin, 2010, published in Doklady Akademii Nauk, 2010, Vol. 434, No. 1, pp. 82–86.

New Data on the Structural Setting and ^{40}Ar/^{39}Ar Age of the MP–LP Metamorphism of the Daulet Formation, Kokchetav Metamorphic Belt, Northern Kazakhstan, and Their Tectonic Interpretation

M. M. Buslov, F. I. Zhimulev, and A. V. Travin

Presented by Academician N.L. Dobretsov December 3, 2009

Received December 21, 2009

DOI: 10.1134/S1028334X10090023

Ultra-high-pressure (UHP) and high-pressure (HP) metamorphic complexes in continental subduction zones are spatially associated with younger medium-pressure (MP) and low pressure (LP) metamorphic rocks [1]. It is a controversial question whether these MP–LP rocks are formed by the contact effect of exhumed hot nappe stack of UHP–HP rocks on the underlying rocks (by analogy with metamorphic base of obducted ophiolite allochthon) or result from later syncollisional metamorphism related to crustal thickening and granite magmatism. MP and LP metamorphic complexes with inverted metamorphic zoning are known in the collisional Himalaya nappe-thrust system [2, 3]. Structurally, they are confined to the overthrusting of the Himalayas onto the Indian continent along the Main Central Thrust. The MP (garnet–kyanite–staurolite) and LP (sillimanite–biotite and biotite) rocks were formed at the initial stage of thrusting (25–15 Ma) and exhumed to the surface by later thrusts and denudation [3].

In order to explain the reasons for MP–LP metamorphism, it is necessary to determine its age. This determination will allow a correlation of this metamorphic event with a definite stage in the geodynamic evolution of the region, in particular, with retrograde metamorphism of UHP–HP rocks, which records their exhumation under LP metamorphic conditions.

One of the reference metamorphic complexes, which combines the UHP–HL and MP–LP rocks, is the Kokchetav metamorphic belt (KMB) in Northern Kazakhstan. Among UHP–HP rocks of this belt are coesite and diamondiferous gneisses and schists, as well as eclogites. According to [4, 5], KMB (Fig. 1) represents a tectonic collage of repeatedly deformed fragments of the Precambrian Kokchetav continent and Vendian–Cambrian megamelange. The megamelange belt is a contrasting structure, consisting of slices and blocks of UHP–HP rocks, which are separated by tectonic nappes of MP–LP metamorphosed rocks. Five terranes containing UHP and HP rocks are distinguished within the belt: Barchi, Kumdy-Kol, Sulu-Tube, Enbek-Berlyk, and Kulet (Fig. 1). These terranes differ in terms of petrographic composition and P–T–t metamorphic paths. The diamondiferous rocks formed at $P = 40–70$ kbar and $T = 1100–1200°C$ were recovered by boreholes in the Kumdy-Kol and Barchi terranes [4, 5]. The metamorphic rocks of the Kulet and Sulu-Tube terranes lack diamonds, but locally contain coesite (in the area south of Lake Kulet). Unlike the Kumdy-Kol terrane, these terranes lack metacarbonate rocks, but contain interlayers of talc-garnet, talc–phengite, and other high-Mg rocks. The rocks of the Barchi and Kumdy-Kol terranes are mainly made up of metasedimentary rocks, which have analogues in the sedimentary cover of the Kokchetav microcontinent [5]. In particular, the diamondiferous metapelites and metacarbonate rocks could be metamorphosed analogues of bitumen- and graphite-rich black shales and dolomites, which occur in the Sharyk Formation at the base of the sedimentary cover of the microcontinent [6].

The aforementioned terranes also contain metamorphosed analogues of the basement rocks of the microcontinent, which are represented by mylonitized granite–gneisses with eclogite lenses. In the Kumdy-Kol terrane, they are partially remelted and penetrated by lenses, veins, and injection migmatites of later granites; the analogous rocks in the Sulu-Tube and Kulet terranes were variably sheared and mylonitized. As a result, the granite gneisses were transformed into garnet–mica schists containing

Institute of Geology and Mineralogy, Siberian Branch, Russian Academy of Science, Novosibirsk, pr. Akad. Koptyuga 3, Novosibirsk, 630090 Russia
e-mail: Misha@uiggm.nsc.ru

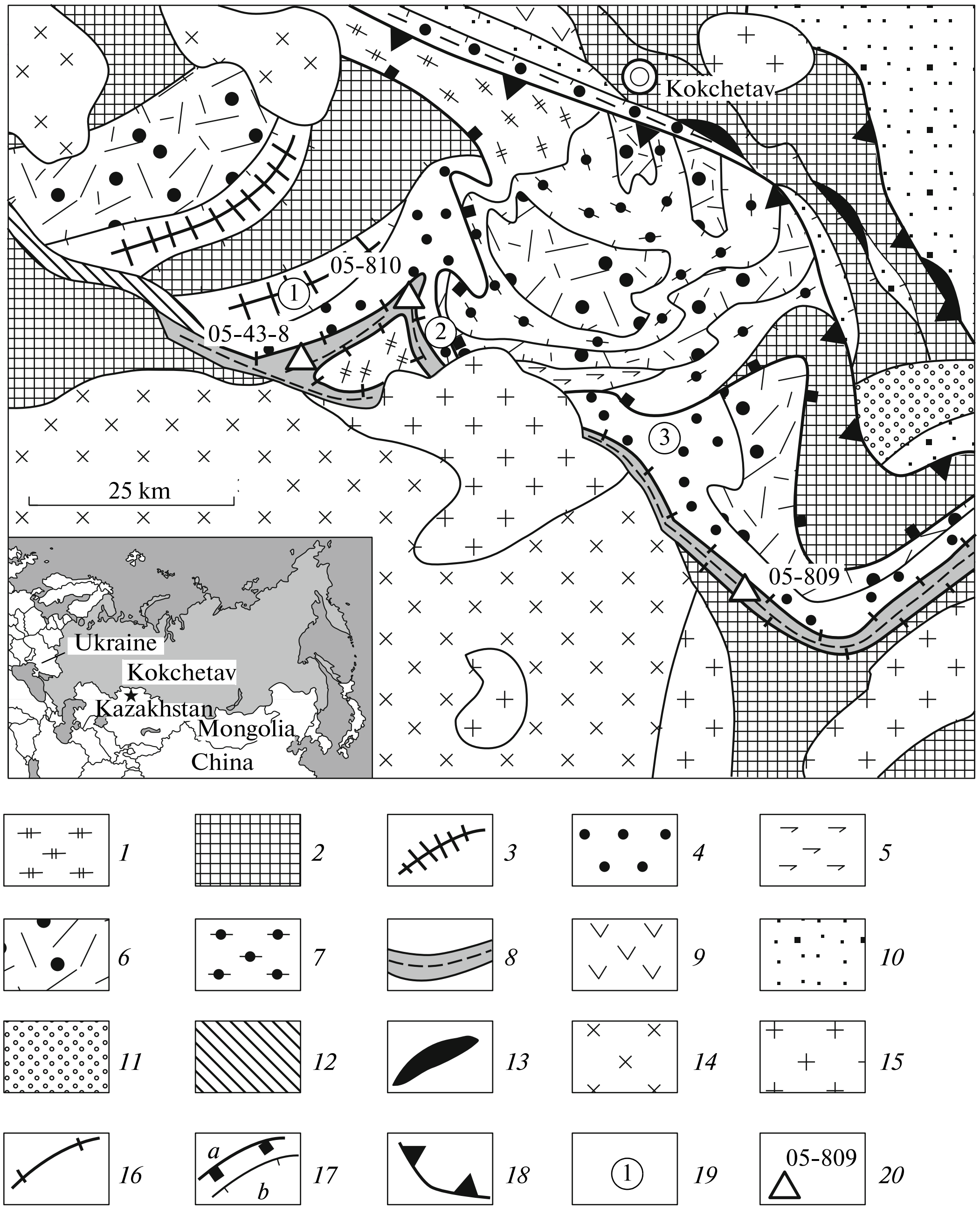

Fig. 1. Geological scheme of the western and central parts of the Kokchetav metamorphic belt. (*1*) Precambrian granite gneisses of the Kokchetav microcontinent basement; (*2*) Late Precambrian dolomites and quartzose metasandstones, respectively, of the Sharyk and Kokchetav formations of the cover of the Kokchetav microcontinent; (*3–7*) Kokchetav UHP–HP metamorphic belt: (*3*) coesite–diamondiferous gneisses and schists, eclogites, (*4*) coesite eclogites, eclogites, and garnet amphibolites in the micaceous schists; (*5*) garnet peridotites, eclogites, amphibolites, (*6*) granite gneisses with eclogite boudins, (*7*) garnet–kyanite schists (mylonites and blastomylonites) with boudins of garnet amphibolites (Berlyk Formation); (*8*) andalusite–cordierite–biotite schists (the Daulet Formation); (*9*) Precambrian dacites and rhyolites; (*10*) Early–Middle Ordovician siliceous–terrigenous, and volcanogenic sedimentary rocks of the Stepnyak paleoisland zone; (*11*) Middle–Late Ordovician molasse; (*12*) alkaline syenites, pyroxenites, and carbonatites of the Krasnomaiskii alkaline-ultrabasic complex; (*13*) serpentinzied ultramafic rocks of the Shchuchinskii ophiolite belt; (*14*) Ordovician granites; (*15*) Devonian granites; (*16*) Cambrian thrusts, the dynamic of which is marked by the andalusite–cordierite–biotite schists of the Daulet Formation; (*17*) frontal thrust of the Early Ordovician tectonic nappe (*a*), thrusts between tectonic nappes (*b*); *(18)* Ordovician thrusts bounding the North Kokchetav tectonic zone; (*19*) location of the terranes of the Kokchetav Metamorphic Belt considered in this work: (1) Kumdy-Kol, (2) Sulu-Tube, (3) Kulet; (*20*) localities and numbers of samples of the Daulet Formation dated by $^{40}Ar/^{39}Ar$ method.

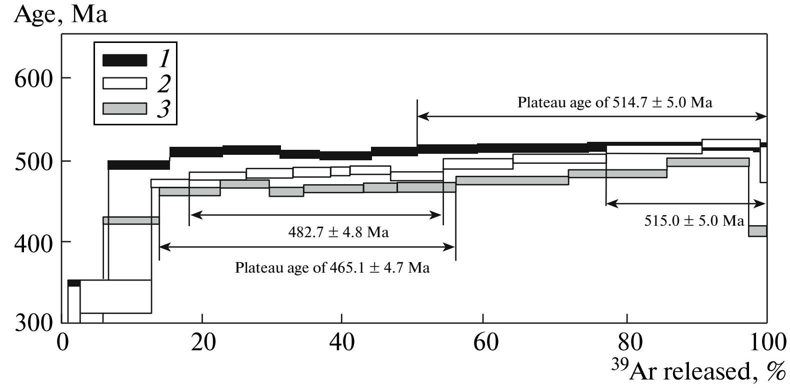

Fig. 2. Age $^{40}Ar/^{39}Ar$ spectra on biotite from schists of the Daulet Formation (carried out by A.V. Travin at the Institute of Geology and Mineralogy, Siberian Branch, Russian Academy of Sciences). (*1*) Sample 05-810; (*2*) sample 05-43-8; (*3*) sample 05-809.

rounded bodies of eclogites, garnet amphibolites, and amphibolites. For instance, garnet–mica schist enclosing bodies of eclogites and other rocks (Sulu-Tube terrane) are exposed in the area of Chaglinka Settlement. They separate the Kumdy-Kol and Sulu-Tube terranes (Fig. 1).

The formation of KMB is related to the Cambrian subduction, exhumation of UHP rocks in the form of lenses and slices with participation of felsic melts at the first stage of collision in the Early–Middle Cambrian, and exhumation of metamorphosed crustal fragments (UHP–HP rocks) to the surface at the second stage of the microcontinent–island arc collision in the Early Ordovician [4, 5, 7]. The Early Ordovician collisional stage was responsible for the formation of late tectonic nappes in the KMB structure and nappe-thrusts in the junction zone between the KMB and Ordovician Stepnyak island arc [4, 7]. The MP–LP rocks of the Kokchetav metamorphic belt are represented by the Daulet Formation. The predominant rocks of the latter are andalusite–garnet–biotite and andalusite–cordierite–biotite schists containing numerous blocks of marbles and plagioclase–diopside rocks. The schists of the Daulet Formation do not contain eclogites and other high-pressure rocks. The P–T parameters of their metamorphism are estimated at 600–650°C and 2 kbar, though rocks also experienced early metamorphism at T = 600–650°C and pressure of 4–5 kbar with formation of garnet and staurolite [4, 8]. Japanese scientists interpreted the rocks of the Daulet Formation as a footwall inverted metamorphic sequence, which was produced by thrusting of the exhumed nappe package of hot UHP–HP rocks on the rocks of the Kokchetav microcontinent [8].

Geological mapping and geochronological dating revealed that the Middle–Late Cambrian exhumation stage of UHP–HP rocks was related to the formation of MP–LP rocks, which are structurally confined to the thrust zone between UHP–HP rocks and the large fragment of the Kokchetav microcontinent (Fig. 1). East of the Chaglinka settlement (sample locality 05-43-8, Fig. 1), the rocks of the Daulet Formation compose a domal core many hundreds of meters thick. It separates the autochthonous Precambrian granite–gneisses and overthrusted muscovite schists with eclogites intersected by granitoids.

In the northeastern part of the KMB, the UHP–HP–LP rocks are covered by nappe consisting of slices that were juxtaposed in the Early Ordovician [4, 7]. The slices are made up of fragments of microcontinent (basement granite-gneisses with bodies of amphibolized gabbrodiabases and sedimentary cover rocks), as well as their analogues metamorphosed in the subduction zone (mylonitized granite gneisses with bodies of garnet amphibolites and eclogites).

The absence of reliable age dates on the schists of the Daulet Formation prevented their correlation with exhumation of UHP–HP rocks and with granite magmatism in the region. There are only two $^{40}Ar/^{39}Ar$ dates on biotite from biotite–andalusite–cordierite schists of the Daulet Formation: 402 ± 5 and 396 ± 6 Ma (summary in [4]). It should be noted that samples for dating were taken from the Sulu-Tube and Kulet areas located in the vicinity of the granitoid massifs of the Balkashin Complex. Since the isochron Rb/Sr age of the leucocratic granites of the Balkashin Complex accounts for 402 ± 12 Ma [9], the obtained K–Ar bitotite dates on the Daulet schists can be rejuvenated due to intense heating related to the granitoid intrusion. Zoned zircon extracted from the Daulet schists in the Sulu-Tube area defines the core and rim U–Pb ages of 1135 ± 16 Ma and 501 ± 10 Ma, respectively [10]. The core age is interpreted as the protolith age, while the rim age is interpreted to record the timing of LP metamorphism.

We dated biotite taken from schists in three areas of the development of the Daulet Formation, two of which are spaced far (many kilometers) from the Late Ordovician and Early Devonian granitoid massifs of the Zerenda and Balkashin complexes (Fig. 1): (1) sample 05-810 (53°07′04.7″ N, 69°04′15.9″ E) located in the central part of a vast exposure of the Daulet rocks between the Chaglinka and Prirechnoe settlements; (2) sample 05-43-8 (53°05′15.9″ N, 69°01′18.2″ E) located east of the Chaglinka settlement at the base of the Daulet Formation in contact with granite-gneisses; (3) sample 05-809 (52°54′59.9″N, 69°35′53.7″ E) from the stratotype section of the formation located in the southeastern part of KMB, in the vicinity of the Daulet Settlement. Dating results are shown in Fig. 2.

Spectra of samples 05-809 and 05-43-8 (Fig. 2) show a staircase rise, which indicates late rejuvenation of the K/Ar isotope system in biotites. The low-temperature part of the spectra of these samples exhibits intermediate plateaus with ages of 465.1 ± 4.7 and 482.7 ± 4.8 Ma, respectively. The high-temperature part of the spectra of biotite 05-43-8 defines an intermediate three-step plateau with an age of 514.7 ± 5.0 Ma, which is close to the age of 515.0 ± 5.0 Ma obtained for biotite 05-810.

Peak temperatures of metamorphism of UHP–HP rocks in contact with the Daulet Formation did not exceed 600–700°C [4, 11]. Such temperatures of exhumed UHP–HP block are too low to heat the multikilometer-sized rock sequences to close temperatures in the time required to complete metamorphic reactions. We suggest that LP metamorphism at the base of the overthrust nappe stack consisting of UHP–HP rocks and fragments of the microcontinent (Fig. 1) is not due to conductive heating, but was caused by collisional metamorphism during nappe piling at the end of the Cambrian, by analogy with the formation of metamorphic rocks in the zone of the Himalaya Main Central Thrust [1, 2].

In our opinion, the oldest age values of biotite at 514.7 ± 5.0 and 515.0 ± 5.0 Ma correspond to the first stage of MP metamorphism of the rocks of the Daulet Formation with formation of garnet and staurolite. Dates around 482 Ma mark the second metamorphic stage with formation of andalusite and cordierite. The age of the Zerenda granitoid complex, the oldest granitoid complex in the region, is presently reliably determined within the range of 455–440 Ma [12]. Ages obtained for the Daulet Formation are significantly older, which unambiguously indicates that LP-metamorphism of its rocks was not related to the granitoid intrusions.

Micas from the UHP–HP rocks of the Kumdy-Kol terrane yield three $^{40}Ar/^{39}Ar$ dates within the range of 529–525 Ma [13, summary in 4], which is consistent with rapid exhumation of the UHP–MP rocks to depths no more than 10 km by that time. However, some micas from the diamondiferous gneisses define ages within 507–517 Ma [14]. This time in the Kumdy-Kol terrane was marked by intense strike-slip faulting due to the piling of tectonic nappes. These deformations were accompanied by the formation of garnet–micaceous and micaceous schist, mylonitization, partial melting, and crystallization of granite melts [4]. Only one age determination (Sm–Nd mineral isochron age of 522 ± 5 Ma on amphibole–garnet–zoisite rock) is available for high-pressure metamorphism in the Kulet terrane located in the eastern part of KMP [15]. This age is consistent with two $^{40}Ar/^{39}Ar$ dates on muscovite (519 ± 4 Ma) and biotite (521 ± 4 Ma) from high-pressure schists [13]. This indicates that the rocks of the Kulet terrane experienced high-pressure metamorphism 10 Ma later than the rocks of the Kumdy-Kol terrane. In any case, the retrograde metamorphism and exhumation of the rocks of the Kulet terrane up to depths of about 10 km were completed 519 ± 4 Ma. Within a period of 522–519 Ma ago, the main deformations were restricted to the Kulet terrane, the granite gneisses of which were mylonitized and transformed into garnet–micaceous schists. The period of 517–507 Ma marked the time of intense thrust-slip faulting in the Kumdy-Kol terrane. Then (505–499 Ma ago), deformations again spanned the Kulet terrane. We believe that in the Middle–Late Cambrian the main tectonic events and exhumation of UHP–HP rocks occurred in the zone of underthrusting of the Kokchetav microcontinent beneath the KMB, where rocks were squeezed out along fault zones with formation of MP–LP metamorphic rocks of the Daulet Formation.

A series of $^{40}Ar/^{39}Ar$ dates within the range of 492–476 Ma, with most dates falling within 485–480 Ma, was obtained on micas from the garnet–muscovite schists and gneisses that compose the tectonic nappes in the northern part of KMB (Fig. 1) [4, 6]. Dates for biotite and muscovite from the gneisses of the Kumdy-Kol terrane fall in the same interval [13]. These age values could be interpreted as the time of exhumation of the UHP–HP rocks to the upper crustal level and juxtaposition of fragments of the paleosubduction zone of different depths. The low-temperature part of spectra of biotite from the schists of the Daulet Formation contains an intermediate plateau with ages of 482.7 ± 4.8 Ma (sample 05-43-8) and 465.1 ± 4.7 Ma (sample 05-809). These dates mark the period (485–480 Ma) of the formation of the quartz–garnet–muscovite dynamoschists after high-pressure rocks in the northeastern part of KMB (Fig. 1), suprasubduction (?) Early Ordovician ophiolites of the Zlatogorsk Complex, and the Stepnyak island arc [4, 7].

Thus, geological and geochronological data showed that MP–LP rocks of the Daulet Formation are structurally confined to the base of the tectonic nappes, which are made up of rocks of the Kokchetav metamorphic belt and thrusted onto the large fragment of the Kokchetav microcontinent. MP–LP metamorphism in the region occurred long before the Paleozoic granite magmatism at the base of the overthrusted nappe stack. The structural position of LP rocks of the Daulet Formation is similar to that of the metamorphic rocks in the Himalayan Main Central Thrust onto the Indian Continent.

ACKNOWLEDGMENTS

This study was supported by Integration Project 9.21 of the Siberian Branch, Russian Academy of Sciences, "Geodynamic Processes in the Subduction Zones: Thermal Physical (Experimental and Theoretical) Modeling and Comparison with Geological–Geophysical Data," project NSh-5736.2008.5 (under the leadership of N.L. Dobretsov), and the Russian Foundation for Basic Research (project no. 08-05-00733).

REFERENCES

1. J. G. Liou, T. Tsujimori, R. Y. Zhang, et al., Int. Geol. Rev. **46**, 1–27 (2004).
2. Y. Kaneko, J. Geol. Soc. Jap. **103**, 203–226 (1997).
3. M. T. Harrison, M. Grove, O. M. Loveta, and E. J. Catlos, J. Geophys. Res. **103** (B211), 27017–27032 (1998).
4. N. L. Dobretsov, M. M. Buslov, F. I. Zhimulev, et al., Geol. Geofiz. **47** (4), 428–445 (2006).
5. K. Theunissen, N. L. Dobretsov, A. Korsakov, et al., The Island Arc **9**, 284–303 (2000).
6. M. M. Buslov and G. M. Vovna, Geokhimiya, No. 9, 955–964 (2008) [Geochem. Int. **46**, 867 (2008)]
7. I. De Grave, M. M. Buslov, F. I. Zhimulev, et al., Geol. Geofiz. **47** (4), 445–455 (2006).
8. M. Terabayashi, T. Ota, H. Yamamoto, and Y. Kaneko, Int. Geol. Rev. **44** (9), 819–830 (2002).
9. K. N. Shatagin, K. E. Degtyarev, and O. V. Astrakhantsev, Dokl. Akad. Nauk **369** (4), 525–528 (1999) [Dokl. Earth Sci. **369**, 1324 (1999)].
10. I. Katayama, S. Maruyama, C. D. Parkinson, et al., Earth Planet. Sci. Lett. **188**, 185–198 (2001).
11. T. Ota, M. Terabayashi, C. D. Parkinson, and H. Masago, The Island Arc, No. 9, 328–357 (2000).
12. F. A. Letnikov, A. B. Kotov, K. E. Degtyarev, et al., Dokl. Akad. Nauk **424** (2), 222–226 (2009) [Dokl. Earth Sci. **424**, 24 (2009)].
13. B. R. Hacker, A. Calvert, R. Y. Zhang, et al., Lithos **70**, 61–75 (2003).
14. V. S. Shatsky, E. Jagoutz, N. V. Sobolev, et al., Contrib. Mineral. Petrol. **137**, 185–205 (1999).
15. V. S. Shatsky, I. Yagoutts, O. A. Kozmenko, et al., Geol. Geofiz., No. 12, 47–58 (1993).