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THE EARLY ORDOVICIAN AGE OF DEFORMATIONS IN THE KOKCHETAV SUBDUCTION-COLLISION BELT: NEW $^{40}Ar/^{39}Ar$ DATA

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It has been shown by extensive mapping and sampling in the central Kokchetav subduction-collision belt that it is a terrane of a Vendian-Cambrian paleosubduction zone made up of tectonic sheets of Precambrian granite gneisses, Late Precambrian garnet-kyanite-sillimanite-biotite schists with boudins of garnet and garnet-plagioclase amphibolites, and Cambrian mylonitized granite gneisses with boudins of eclogites. The fault zones between tectonic sheets are formed by garnet-quartz-muscovite and quartz-muscovite schists. Along with the central Kokchetav belt, they are isoclinally overfolded southwestward. $^{40}Ar/^{39}Ar$ dating of muscovite from five mica schist samples yielded close plateau and isochron ages of 480–485 Ma (Early Ordovician). The geological and geochronological data confirm the Early Ordovician formation of the nappe-sheet structure of the Kokchetav subduction-collision belt and exhumation of UHP and HP rocks in the middle-upper crust.

Granite-gneisses, eclogites, garnet amphibolites, phengite, geochronology, Kokchetav metamorphic belt, Berlyk Formation

INTRODUCTION

A subduction-collision belt has been recognized in the Kokchetav massif of northern Kazakhstan [1–3]. It contains ultrahigh-pressure coesite-diamondiferous rocks and high-pressure eclogites (UHP-HP rocks), whose formation is related to the subduction of continental crust [1–8]. Recent analysis of the texture and composition of rocks of the Kokchetav subduction-collision belt and geochronological data suggest [1–3] an important role of Early Ordovician processes in its evolution and exhumation of UHP-HP rocks under the crustal conditions. It has been shown that the belt is represented by juxtaposed terranes of the Precambrian Kokchetav microcontinent, Late Cambrian-Early Ordovician accretionary prism (containing island-arc rocks, ophiolites, mylonitized granite gneisses with boudins of eclogites, olistostromes, and turbidites) with Cambrian paleosubduction metamorphic rocks formed at different depths. The tectonic juxtaposing continued until the Late Arenigian-Early Caradocian under the conditions of collision of the Kokchetav microcontinent with the Ordovician Stepnyak island arc. The two-stage subduction (Vendian-Cambrian and Ordovician) and collision (Early Ordovician) led to the formation of a complex nappe-imbricated structure of the Kokchetav subduction-collision belt [1–3].

It contains two large structural units (Fig. 1): a megamelange belt represented by terranes formed at different depths of the paleosubduction zone from 150–200 to 60–30 km, and an accretionary prism formed at depths from 60–30 to 0 km [1–3]. Ar-Ar dating of muscovite schists from faulting zones yields the Early Arenigian age (490–478 Ma) of the accretionary prism [1–3], while chiefly Cambrian stages of exhumation of UHP-HP rocks under the upper mantle and lower crust conditions are dated in the megamelange belt (Kumdy-Kol' and Kulet terranes) [5–15]. In this connection it seems important to determine the age of numerous garnet-quartz-mica and

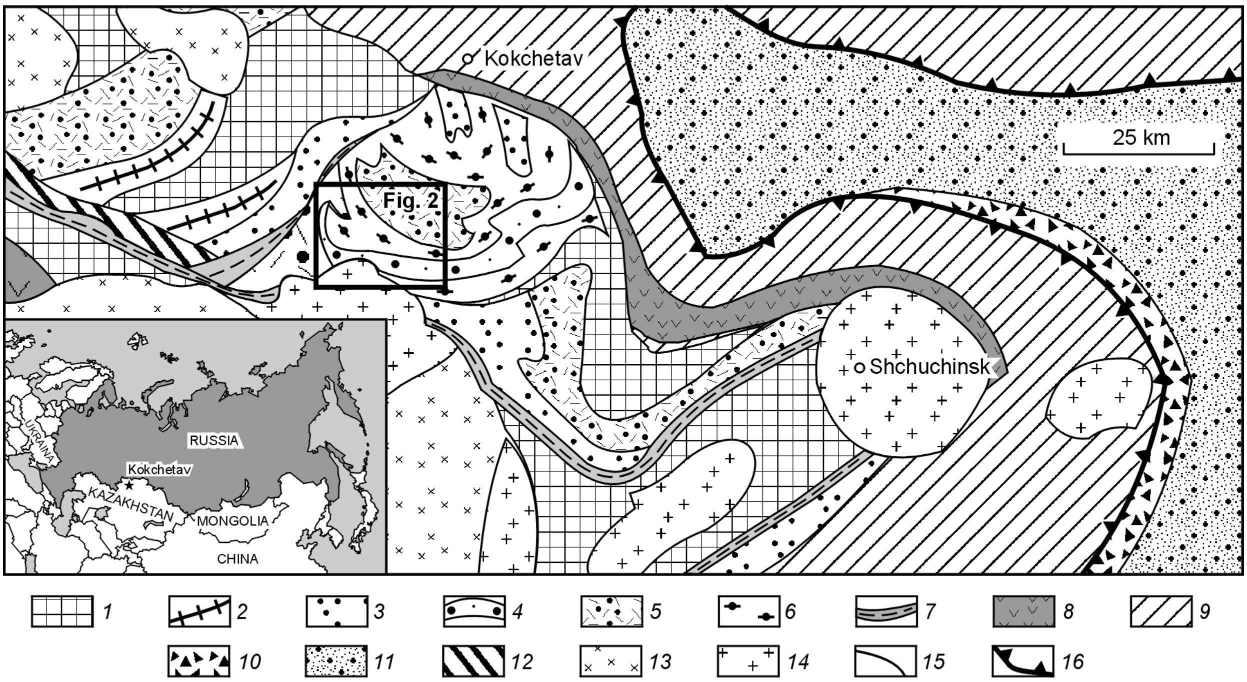

Fig. 1. Schematic terrane structure of the Kokchetav subduction-collision zone (the study area is framed, Fig. 2). ***1*** **— Fragments of sedimentary cover of Kokchetav microcontinent;** ***2–6*** **— megamelange belt (terranes of paleosubduction zone):** ***2*** **— diamondiferous gneisses and coesite eclogites,** ***3*** **— coesite eclogites, eclogites, and garnet amphibolites in mica schists,** ***4*** **— garnet peridotites, eclogites, and amphibolites,** ***5*** **— eclogites and garnet amphibolites in granite gneisses,** ***6*** **— garnet-sillimanite-cordierite schists (mylonites and blastomylonites) with boudins of eclogites and garnet amphibolites;** ***7*** **— garnet-cordierite-biotite schists and gneisses (Daulet Formation);** ***8*** **— Vendian(?) volcanosedimentary rocks;** ***9*** **— Early Ordovician accretionary prism;** ***10*** **— Late Arenigian-Early Caradocian syntectonic olistostrome;** ***11*** **— Ordovician volcanosedimentary rocks of Stepnyak trough;** ***12*** **— Cambrian Krasnomaisky alkali-ultrabasic complex;** ***13*** **— Ordovician granites;** ***14*** **— Devonian granites;** ***15*** **— deformed Late Cambrian-Early Ordovician faults;** ***16*** **— Late Arenigian-Early Caradocian frontal overthrust of Kokchetav massif.**

quartz-mica near-fault schists separating the terranes of the megamelange belt and separate tectonic sheets in them as they record the time of exhumation of UHP-HP rocks under the middle-upper crust conditions.

We have carried detailed geological mapping in the central part of the megamelange belt (stratotype locality of the Berlyk Formation) with sampling of garnet-quartz-micaceous and quartz-micaceous rocks that trace fault zones of the tectonic sheets and slices of the Berlyk terrane (see Figs. 1 and 2). The explored terrane lies between the Sulu-Tobe and Kulet terranes harboring UHP-HP rocks. The Berlyk terrane is named after the Berlyk Formation, which is characterized by high-alumina fine-grained garnet-kyanite-sillimanite-biotite schists containing boudins of eclogites(?), garnet amphibolites, and coronites (garnet amphibolites with garnet coronas around plagioclase and at the boundary with pyroxene). Some authors [6, 7] note that tectonics lenses of granite gneisses with boudins of eclogites and garnet amphibolites occur in the field of occurrence of the Berlyk fine-grained schists.

This paper reports new $^{40}Ar/^{39}Ar$ ages of muscovite from the garnet-quartz-mica and quartz-mica schists developed in fault zones of the Berlyk terrane. The presented ages are some of the results which are planned to be obtained for dating the fault zones separating the terranes of the paleosubduction zone.

GEOLOGIC STRUCTURE OF THE BERLYK TERRANE

Detailed geological dating shows that the Berlyk terrane is composed of a series of tectonic sheets (see Fig. 2) made up of three types of rocks: Late Precambrian fine-grained garnet-kyanite-sillimanite-biotite schists containing boudins of garnet amphibolites with corona structure; mylonitized, conventionally Cambrian granite gneisses with boudins of eclogites and garnet amphibolites; granite gneisses which are probably fragments of the Precambrian

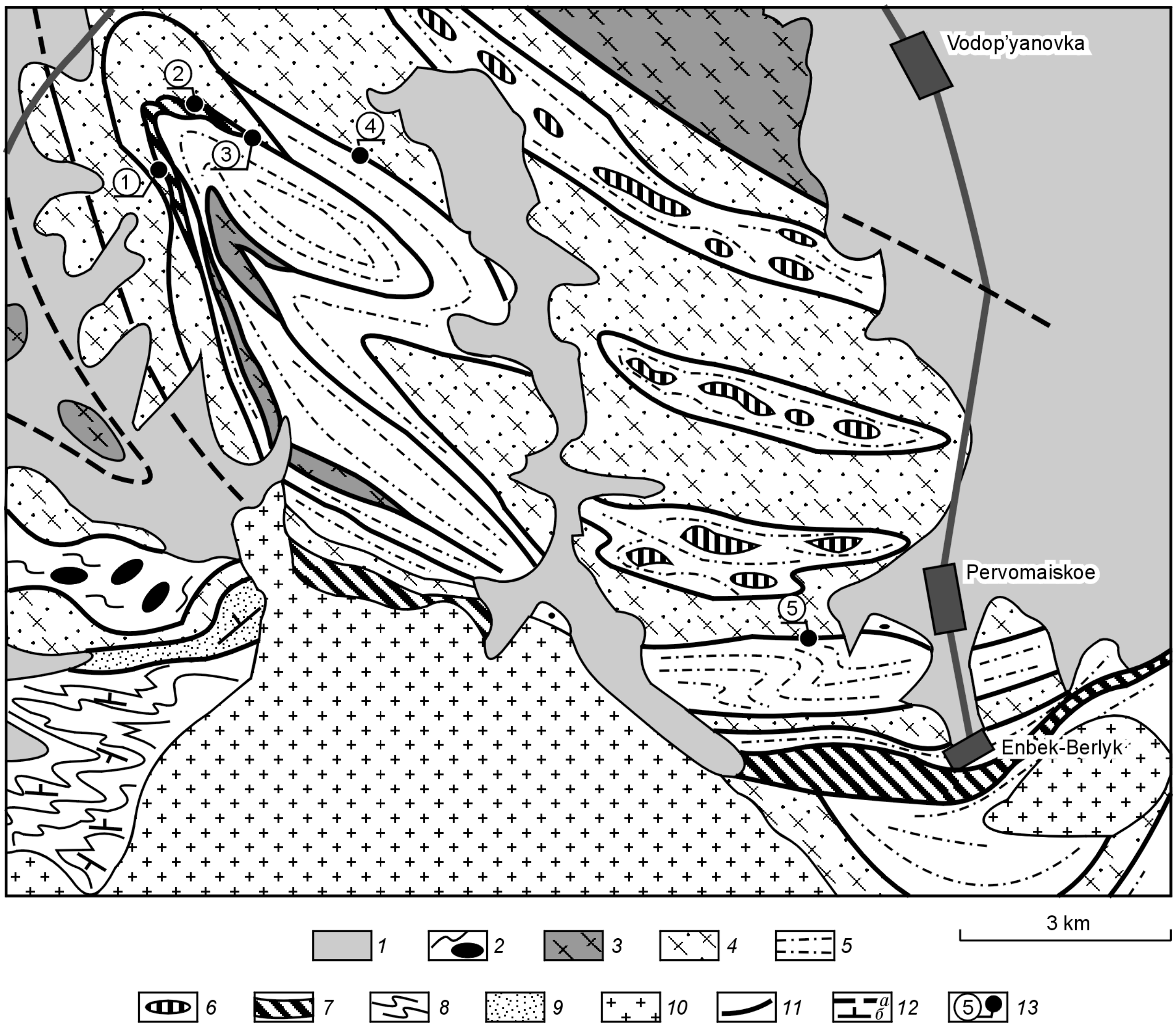

Fig. 2. A tectonic scheme of the Berlyk and adjacent terranes. ***1*** **— Quaternary deposits;** ***2*** **— HP-rocks in micaceous schists;** ***3*** **— granite gneisses of microcontinent basement;** ***4–7*** **— Berlyk terrane (Berlyk Formation):** ***4*** **— mylonitized granite gneisses with bodies of garnet amphibolites and eclogites,** ***5***, ***6*** **— garnet-sillimanite-kyanite-quartz-biotite schists:** ***5*** **— fine-grained,** ***6*** **— coarse-grained in cores of isocline folds,** ***7*** **— alternation of garnet peridotites, garnet pyroxenites, garnet amphibolites, eclogites, and plagioclase-pyroxene rocks;** ***8*** **— quartz sandstones of Kokchetav Formation (microcontinent cover) with layering strike;** ***9*** **— Early-Middle Ordovician(?) cordierite-andalusite-biotite gneisses and schists of Daulet Formation;** ***10*** **— predominantly Ordovician granites, nondifferentiated;** ***11*** **— deformed planes of Early Arenigian faults filled with garnet-quartz-phengite and quartz-phengite schists;** ***12*** **— structure elements:** ***a*** **— supposed faults,** ***b*** **— dips and strikes of layering;** ***13*** **— locations sampled by Ar-Ar method: 1 — Kok2-3, 2 — Kok2-23, 3 — Kok2-7, 4 — Kok2-32, 5 — Kok2-50.**

basement of the Kokchetav microcontinent. The tectonic sheets are separated by zones (few ten meters thick) of quartz-muscovite and garnet-quartz-muscovite schists, which trace the fault planes. The micas occur within the sheets too, especially at their boundaries. The tectonic sheets and fault planes are contorted into large (wing span up to many hundred meters) isoclinal folds. The axes of the folds submerge northeastward at 60–70°. As a rule, the relief well preserves fine-grained garnet-kyanite-sillimanite-biotite schists with bodies of garnet amphibolites, which form largely domal extended structures of the NE and sublatitudinal strike among mylonitized granite gneisses. The faulting zones, especially at the hinges of the domal structures, are characterized by isoclinal folds, with a wing span from few to tens of centimeters, and fine plication.

The garnet amphibolites with coronite structure were formed at 4–7 kbar and 600–680 °C [9]. The same conditions were also established for the garnet-kyanite-biotite-sillimanite schists. The age of metamorphism is not established for safe yet, though some $^{40}Ar/^{39}Ar$ datings [8] indicate the Late Cambrian (565–553 Ma). Another stage of metamorphism and deformations into which the imbricated structure of the Berlyk Formation was transformed is accompanied by the formation of garnet-quartz-mica and quartz-mica schists separating tectonic slices of different compositions. The age of muscovites indicating the time of formation of the imbricated structure was determined by the $^{40}Ar/^{39}Ar$ method of dating.

RESULTS OF ^{40}Ar/^{39}Ar DATING

We report here $^{40}Ar/^{39}Ar$ ages of five muscovite samples from garnet-quartz-mica and quartz-mica schists. Sample description and location are listed in Table 1, and analytical data of $^{40}Ar/^{39}Ar$ stepwise heating of muscovites, in Table 2. About 1–2 mg of pure (inclusion-free, monomineralic) muscovite flakes (generally 100–200 μm in size) were selected by handpicking from muscovite separates under a powerful zoom stereomicroscope and packed in pure Cu-foil for irradiation. Irradiation was performed at the Oregon State University TRIGA reactor facility for 9 hours at 1000 kW. A sanidine age standard from the Taylor Creek rhyolite with an age of 27.92±0.17 Ma was used (USGS standard 85G003). The $^{40}Ar/^{39}Ar$ analyses were conducted at the Stanford University Noble Gas Laboratory.

Argon spectra and an inverse isochron for each sample are depicted in Fig. 3. Because of bad statistical fits, no inverse isochron is given for sample 3-27. The other four samples exhibit relatively large and flat plateaus, and isochron ages were determined for them. The values of age plateaus and isochron age are very close and indicate the Early Ordovician age of muscovites, 480–485 Ma. The bad isochron fit for sample 3-27 and the slightly saddle-shaped spectrum are most likely due to the presence of excess Ar in this sample. The obtained data unambiguously indicate that the garnet-quartz-micaceous and quartz-micaceous schists were formed in the interval 480–485 Ma (Fig. 4).

DISCUSSION AND CONCLUSIONS

Dobretsov et al. [1–3] believe that the subduction of the lithosphere of the Paleoasian ocean and the collision of the Kokchetav microcontinent with island arcs ultimately determined the formation and exhumation of the UHP-HP rocks. Initially, in the Vendian-Early Cambrian, the microcontinent subsided into the subduction zone to depths of 150–200 km, which led to the UHP-HP metamorphism (maximum at about 535 Ma) and to partial melting of rocks. In the following stage (535–528 Ma) the generated acidic melts containing UHP-HP rocks arrived the base of the accretionary prism (depths of 60–30 km). In the period 528–500 Ma the UHP-HP rocks ascended along the fault structures of the lower crust after the subduction zone had been wedged by the Kokchetav microcontinent. In the period 500–480 Ma, the UHP-HP rocks entered the upper crust. This process led to the formation of the Kokchetav subduction-collision zone and accretionary wedge separated by zones of garnet-mica and mica schists, blastomylonites and mylonites. The Late Arenigian-Early Caradocian collision processes between the microcontinent and island arc (480–460 Ma) led to the overriding of the Kokchetav subduction-collision zone on the fore-arc trough of the Stepnyak island arc.

Dobretsov et al. [1–3] characterized the $^{40}Ar/^{39}Ar$ age of muscovites in the interval 490–478 Ma from the fault zones of the accretionary prism situated between the Kokchetav megamelange zone and Stepnyak fore-arc

Table 1

Coordinates of Sampling for Ar/Ar Dating of Muscovites

Sample (number in Fig. 3)	Schist	Latitude (northern)	Longitude (eastern)	Height, m
Kok3-3 (1)	Garnet-quartz-muscovite	53°08′12″	069°11′44″	338
Kok3-23 (2)	»	53°08′50′24″	069°12′40′24″	298
Kok3-27 (3)	»	53°08′24′24″	069°12′47′24″	319
Kok3-32 (4)	Quartz-muscovite	53°08′16′24″	069°14′49′24″	318
Kok3-50 (5)	»	53°04′24″	069°20′13′24″	345

Table 2

Analytical Results of $^{40}Ar/^{39}Ar$ Stepwise Heating of Muscovites

T, °C	$^{36}Ar/^{39}Ar$ (1σ)	$^{37}Ar/^{39}Ar$ (1σ)	^{39}Ar, %	$^{40}Ar^{*}/^{39}Ar$ (1σ)	Age, Ma
1	2	3	4	5	6
Kok3-3, muscovite, J = 0.0023658					
700	0.0206 (0.0006)	0.2796 (0.1686)	0.64	109.74 (0.26)	416.41 ± 2.64
800	0.0098 (0.0004)	0.3026 (0.1311)	0.82	132.08 (0.22)	490.55 ± 2.16
850	0.0082 (0.0077)	0.3851 (2.3495)	0.04	132.13 (3.29)	490.72 ± 32.09
900	0.0143 (0.0042)	0.3059 (1.2145)	0.09	133.28 (1.85)	494.45 ± 18.05
950	0.0043 (0.0001)	0.0536 (0.0116)	10.11	130.63 (0.15)	485.83 ± 1.43
1000	0.0031 (0.0001)	0.1099 (0.0273)	4.21	130.30 (0.11)	484.76 ± 1.04
1025	0.0051 (0.0003)	0.2669 (0.0776)	1.45	128.84 (0.14)	479.99 ± 1.40
1050	0.0070 (0.0004)	0.3797 (0.1188)	0.93	129.91 (0.25)	483.48 ± 2.43
1075	0.0068 (0.0005)	0.3512 (0.1394)	0.81	129.27 (0.22)	481.40 ± 2.12
1100	0.0070 (0.0005)	0.4035 (0.1429)	0.79	130.57 (0.30)	485.63 ± 2.98
1120	0.0057 (0.0004)	0.3040 (0.1174)	0.96	130.07 (0.20)	484.02 ± 1.94
1140	0.0039 (0.0003)	0.2031 (0.0918)	1.24	130.40 (0.18)	485.07 ± 1.77
1170	0.0027 (0.0003)	0.1575 (0.0632)	1.85	130.17 (0.14)	484.35 ± 1.36
1200	0.0018 (0.0003)	0.1765 (0.0786)	1.46	130.34 (0.16)	484.88 ± 1.53
1250	0.0027 (0.0004)	0.3834 (0.1346)	0.85	131.16 (0.21)	487.56 ± 2.10
1300	0.0026 (0.0009)	0.3924 (0.2621)	0.44	130.90 (0.38)	486.70 ± 3.75
1400	0.0012 (0.0014)	0.6804 (0.4112)	0.28	132.54 (0.62)	492.04 ± 6.07
Kok3-23, muscovite, J = 0.0023600					
700	0.0484 (0.0008)	0.3743 (0.1442)	0.75	104.86 (0.29)	398.90 ± 2.97
800	0.0142 (0.0005)	0.3109 (0.1216)	0.88	130.54 (0.22)	484.50 ± 2.13
850	0.0112 (0.0003)	0.2642 (0.0797)	1.34	131.94 (0.16)	489.03 ± 1.58
900	0.0119 (0.0002)	0.1713 (0.0437)	2.52	129.83 (0.11)	482.19 ± 1.08
950	0.0096 (0.0001)	0.0873 (0.0138)	8.15	129.70 (0.13)	481.77 ± 1.30
1000	0.0039 (0.0001)	0.1053 (0.0165)	6.81	129.33 (0.12)	480.55 ± 1.21
1025	0.0063 (0.0002)	0.2349 (0.0390)	2.87	129.21 (0.11)	480.17 ± 1.04
1050	0.0083 (0.0003)	0.2767 (0.0660)	1.68	128.28 (0.14)	477.12 ± 1.35
1075	0.0091 (0.0003)	0.3315 (0.0850)	1.31	129.12 (0.15)	479.87 ± 1.51
1100	0.0085 (0.0003)	0.3064 (0.0834)	1.32	130.19 (0.20)	483.35 ± 1.95
1120	0.0072 (0.0003)	0.2428 (0.0628)	1.76	128.51 (0.15)	477.87 ± 1.50
1140	0.0051 (0.0002)	0.1463 (0.0450)	2.48	129.27 (0.11)	480.37 ± 1.12
1170	0.0030 (0.0001)	0.1400 (0.0377)	2.97	129.56 (0.11)	481.31 ± 1.09
1200	0.0033 (0.0003)	0.2603 (0.0762)	1.46	129.06 (0.15)	479.67 ± 1.45
1250	0.0033 (0.0006)	0.4864 (0.1625)	0.69	129.21 (0.27)	480.15 ± 2.69
1300	0.0036 (0.0013)	0.7242 (0.3577)	0.31	128.74 (0.56)	478.63 ± 5.45
1400	0.0083 (0.0022)	0.9288 (0.6240)	0.18	127.77 (0.96)	475.46 ± 9.44
Kok3-27, muscovite, J = 0.0023566					
700	0.0097 (0.0005)	0.2360 (0.1353)	0.75	128.57 (0.41)	477.47 ± 2.20
800	0.0057 (0.0007)	0.2004 (0.2083)	0.50	134.80 (0.27)	497.67 ± 3.22
850	0.0042 (0.0004)	0.1984 (0.1043)	0.99	134.74 (0.30)	497.50 ± 2.46
900	0.0036 (0.0002)	0.0969 (0.0544)	1.97	131.82 (0.13)	488.04 ± 2.01
950	0.0020 (0.0001)	0.0629 (0.0186)	5.87	129.99 (0.12)	482.11 ± 1.07
1000	0.0019 (0.0002)	0.1371 (0.0374)	2.86	129.77 (0.17)	481.39 ± 1.14
1025	0.0032 (0.0003)	0.2859 (0.0971)	1.10	129.33 (0.27)	479.93 ± 1.73

Table 2 **(continued)**

1	2	3	4	5	6
1050	0.0032 (0.0004)	0.2333 (0.1131)	0.94	129.53 (0.26)	480.59 ± 1.94
1075	0.0030 (0.0004)	0.2199 (0.1197)	0.89	130.33 (0.35)	483.21 ± 2.38
1100	0.0027 (0.0004)	0.1857 (0.1058)	1.02	131.06 (0.30)	485.57 ± 2.55
1120	0.0021 (0.0003)	0.1874 (0.0900)	1.19	130.33 (4.79)	483.21 ± 1.94
1140	0.0019 (0.0003)	0.1588 (0.0813)	1.31	131.29 (0.20)	486.35 ± 1.90
1170	0.0020 (0.0004)	0.1939 (0.1048)	1.01	131.12 (0.27)	485.76 ± 2.28
1200	0.0006 (0.0008)	0.3404 (0.2187)	0.50	131.41 (0.36)	486.71 ± 4.39
1250	0.0012 (0.0018)	0.6237 (0.4788)	0.22	131.78 (0.82)	487.90 ± 7.72
1300	0.0003 (0.0039)	0.8685 (1.0930)	0.10	132.56 (1.72)	490.45 ± 15.91
1400	0.0043 (0.0048)	0.3202 (1.3048)	0.08	142.14 (2.29)	521.21 ± 19.39
Kok3-32, muscovite, J = 0.0023579					
700	0.0346 (0.0011)	0.1562 (0.3150)	0.35	88.90 (0.41)	343.32 ± 4.38
800	0.0065 (0.0006)	0.0873 (0.1684)	0.66	133.52 (0.27)	493.79 ± 2.59
850	0.0044 (0.0005)	0.1221 (0.1408)	0.80	133.72 (0.30)	494.44 ± 2.92
900	0.0046 (0.0002)	0.0962 (0.0584)	1.94	129.77 (0.13)	481.60 ± 1.28
950	0.0018 (0.0001)	0.0771 (0.0218)	5.31	129.90 (0.12)	482.02 ± 1.22
1000	0.0022 (0.0002)	0.1862 (0.0565)	2.02	129.75 (0.17)	481.54 ± 1.66
1025	0.0030 (0.0005)	0.3413 (0.1445)	0.77	130.13 (0.27)	482.78 ± 2.63
1050	0.0032 (0.0006)	0.4207 (0.1789)	0.63	128.80 (0.26)	478.46 ± 2.55
1075	0.0041 (0.0006)	0.3697 (0.1853)	0.61	129.29 (0.35)	480.08 ± 3.39
1100	0.0046 (0.0005)	0.2772 (0.1582)	0.72	129.58 (0.30)	481.00 ± 2.96
1120	0.0131 (0.0115)	0.8038 (3.4231)	0.03	138.08 (4.79)	508.47 ± 46.16
1140	0.0017 (0.0004)	0.1542 (0.1250)	0.90	129.45 (0.20)	480.57 ± 1.93
1170	0.0016 (0.0004)	0.1773 (0.1234)	0.92	130.99 (0.27)	485.58 ± 2.63
1200	0.0012 (0.0008)	0.1800 (0.2389)	0.47	129.67 (0.36)	481.27 ± 3.49
1250	0.0026 (0.0017)	0.6656 (0.5154)	0.22	130.79 (0.82)	484.92 ± 7.97
1300	0.0034 (0.0041)	1.1214 (1.2093)	0.09	129.34 (1.72)	480.22 ± 16.83
1400	0.0006 (0.0050)	1.4362 (1.5211)	0.01	133.26 (2.29)	492.96 ± 22.27
Kok3-50, muscovite, J = 0.0023551					
700	0.0491 (0.0008)	1.0721 (0.2040)	0.43	86.41 (0.29)	334.19 ± 3.09
800	0.0150 (0.0004)	0.4675 (0.1069)	0.82	126.76 (0.20)	471.30 ± 1.92
850	0.0128 (0.0003)	0.4159 (0.0849)	1.04	129.73 (0.17)	480.97 ± 1.67
900	0.0109 (0.0002)	0.2216 (0.0466)	1.94	128.76 (0.12)	477.82 ± 1.17
950	0.0074 (0.0001)	0.0800 (0.0111)	8.21	129.36 (0.11)	479.77 ± 1.10
1000	0.0040 (0.0001)	0.1711 (0.0238)	3.84	129.32 (0.10)	479.64 ± 0.97
1025	0.0088 (0.0003)	0.4641 (0.0719)	1.23	128.80 (0.20)	477.95 ± 1.97
1050	0.0096 (0.0005)	0.5229 (0.1068)	0.84	127.95 (0.20)	475.19 ± 1.91
1075	0.0096 (0.0004)	0.5880 (0.1210)	0.75	128.02 (0.20)	475.40 ± 1.93
1100	0.0104 (0.0004)	0.6356 (0.1209)	0.75	128.64 (0.24)	477.41 ± 2.34
1120	0.0086 (0.0004)	0.5712 (0.1123)	0.80	128.43 (0.20)	476.75 ± 1.93
1140	0.0075 (0.0003)	0.4795 (0.0854)	1.05	129.88 (0.20)	481.48 ± 1.96
1170	0.0049 (0.0002)	0.2875 (0.0549)	1.70	128.88 (0.12)	478.21 ± 1.18
1200	0.0038 (0.0003)	0.3738 (0.0742)	1.24	129.81 (0.13)	481.23 ± 1.27
1250	0.0045 (0.0005)	0.6214 (0.1301)	0.70	130.14 (0.26)	482.32 ± 2.55
1300	0.0054 (0.0011)	1.2319 (0.3008)	0.31	127.52 (0.44)	473.79 ± 4.30
1400	0.0055 (0.0015)	1.5817 (0.4052)	0.23	129.31 (0.69)	479.62 ± 6.73

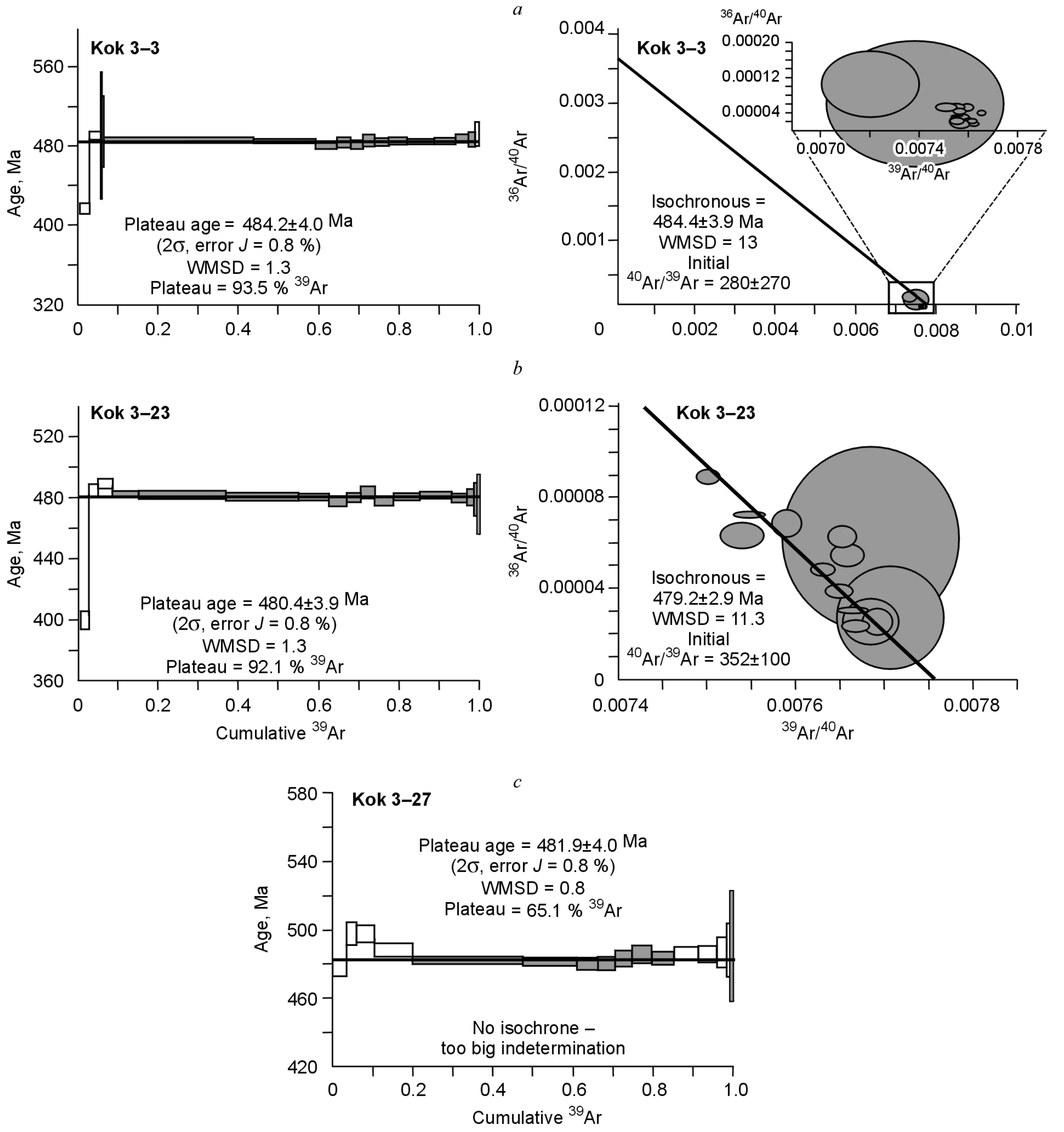

Fig. 3 (to be continued).

trough. These ages are treated as the time of manifestation of a collision tectonic event related to the transition of the continental subduction into the microcontinent-island arc collision. Undoubtedly, this interval of time, characterizing the backward flows in the accretionary prism should also be recorded in the paleosubduction zone equally in the manifestation of structural forms and in the retrograde metamorphism of UHP-HP rocks. Travin [16] used the Ar-Ar method to date minerals from the field of occurrence of the Berlyk Formation rocks including amphibole from garnet amphibolite with coronite structure and biotite from eclogite-bearing granite gneisses and obtained ages of 553±26 and 531±21 Ma, respectively. These ages correspond to the stage of the initial subsidence of the rocks of the Kokchetav microcontinent into the zone of subduction and can be evidence of the formation of garnet-kyanite-sillimanite-biotite schists and garnet amphibolites in the upper part of the paleosubduction zone (P = 4–7 kbar and T = 600–680 °C). The muscovite developed after the same granite gneisses has an age of

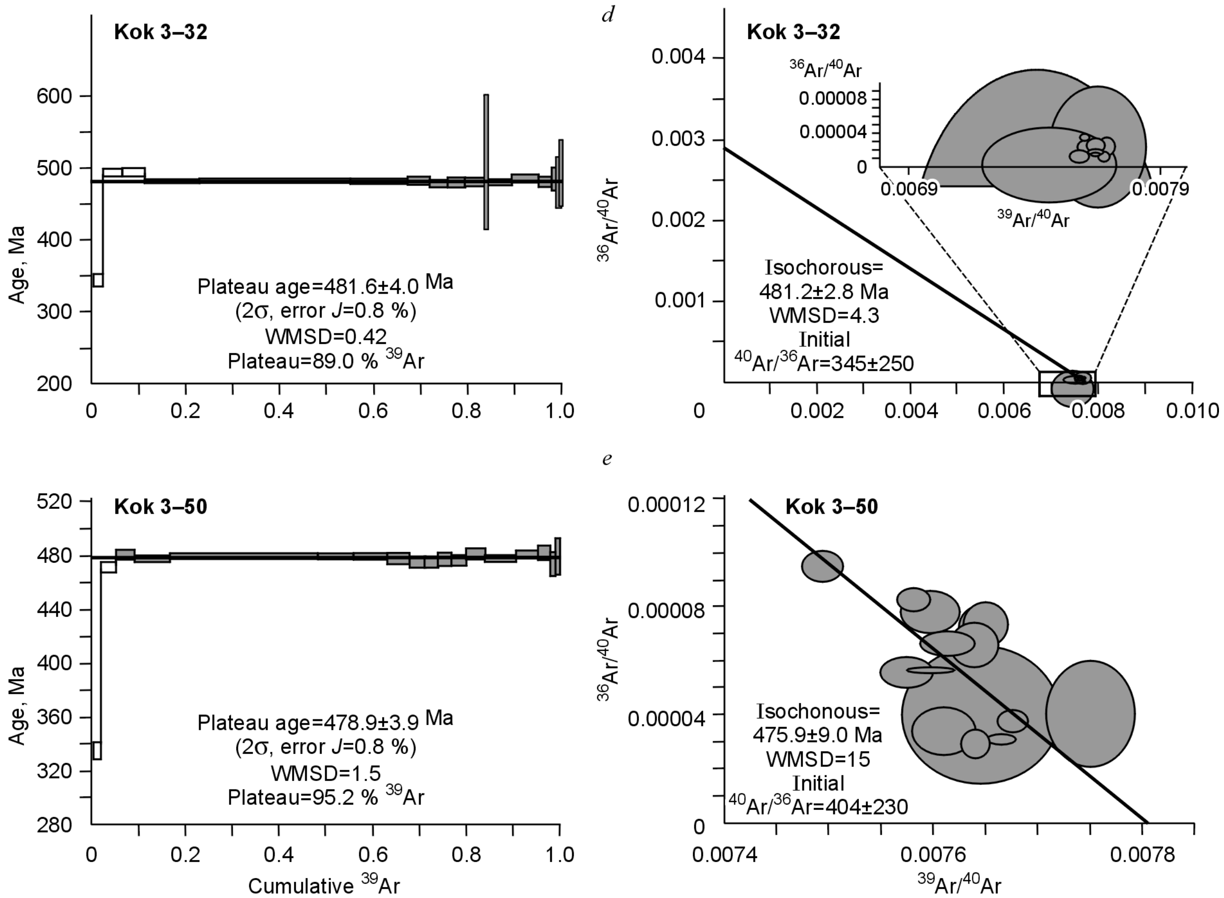

Fig. 3. Results of Ar-Ar dating of samples. *a* — Kok3-3, *b* — Kok3-23, *c* — Kok3-27, *d* — Kok3-32, *e* — Kok3-50. On the left, age spectra obtained by stepwise heating are shown. All age plateaus include 0.8% estimations of irradiation errors. Only hatched steps of plateaus are used in age calculation. On the right show inversion isochronous age is shown in $^{39}Ar/^{40}Ar$–$^{36}Ar/^{40}Ar$ system, except for Kok3-27.

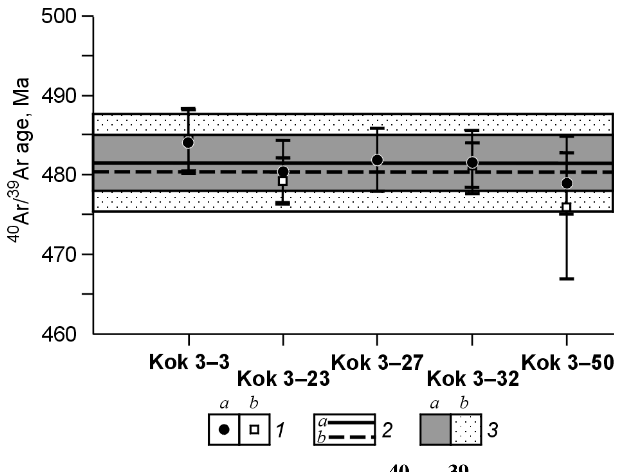

Fig. 4. Diagram of distribution of $^{40}Ar/^{39}Ar$ ages of the studied samples. *1* — values after age plateau (*a*) and isochronous age (*b*); *2* — average after five samples (*a*) and four samples (*b*); *3* — confidence intervals for average ages (2σ) after plateau (*a*) and isochronous ages (*b*).

486±9 Ma, and the muscovite developed after garnet-kyanite-sillimanite schist (containing dated garnet amphibolite), 478±5 Ma [16]. The muscovite ages are evidently superimposed on the Berlyk Formation rocks, which have a complicated structure-metamorphic history and form a folded imbricated structure.

On the basis of geochronological data and structural features one can recognize three stages in the structuring of the Berlyk terrane: early (Late Cambrian) related to the formation of garnet-kyanite-quartz schists and garnet amphibolites with typical linearity along stretched crystals of kyanite [7, 8], intermediate (Early Arenigian)—juxtaposition of heterochronous tectonic sheets with the formation of the imbricated structure of the terrane as well as garnet-quartz-micaceous and quartz-micaceous schists in near-fault zones, and the late stage—deformation of the imbricated structure and formation of large southwest-overturned isoclinal domal folds. Our data on the age of muscovites from faulting zones and the age of muscovites from the interior of the Berlyk sheets [16] indicate the Early Arenigian age of the second stage of deformations.

The data obtained well agree with the opinion of some authors [7, 8] that the exhumation of the Kokchetav metamorphic melange was not single-act and various tectonic mechanisms contributed differently to the uplift of metamorphic rocks. In particular, for the fine-grained rocks of the Berlyk Formation also three stages of deformations have been revealed: early—with manifestation of mineral linearity owing to the orientation of small kyanite crystals, intermediate—characterized by fine-wave folding, and late—expressed in intense lamination with the appearance of sillimanite. Comparison of these stages with the above-mentioned ages and structural data suggests that the early stage corresponds to the age of the Cambrian initial subduction metamorphism, the intermediate stage corresponds to the Late Arenigian period of the formation of the imbricated structure of the Berlyk terrane, and the late stage coincides with the manifestation of folding and intense lamination. The intermediate and late stages coincide in age with the time of collision of the Kokchetav microcontinent with the Ordovician Stepnyak island arc [1–3].

Thus, our new geochronological data and data on the structure of the Berlyk terrane permitted us to record the Early Arenigian (480–485 Ma) tectonic stage in the formation of the nappe-imbricated strcuture of the Kokchetav subduction-collision belt and exhumation of UHP-HP rocks which proceeded under the conditions of back flows in the paleosubduction zone.

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