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GEOLOGY

Mesoproterozoic Granitoids of the Kokchetav Microcontinent Basement

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The Kokchetav microcontinent or the Kokchetav terrain distinguished by E.D. Shlygin [1] is a Precambrian subplatform structure within the completed and uncompleted Caledonides. The Precambrian Kokchetav microcontinent is well distinguished in the geophysical fields, where the thickness of the Earth's crust within the Continent ranges from 42 to 45 km [2], and the bounds of the microcontinent are traced by deep tectonic structures. Metamorphic rocks, developed within the microcontinent are divided into two series. The thickest lower (Zerendinskaya) series [3] consists mainly of metamorphic rocks of amphibolite facies metamorphism. The upper (Sharykskaya) series is composed of Late Precambrian rocks metamorphosed under the green schist metamorphism. Both these series are separated by metamorphic and stratigraphic unconformity [3]. Precambrian rocks of both series were intruded by anomalously large masses of the Caledonian granitoids [4, 8]. The age of the rocks of the Kokchetav microcontinent remains a debatable topic. The analysis of the model age of the metaterrigenous rocks of the Zerendinskaya series (2.1–2.5 Ba) [4] and diamond-bearing gneisses of Kumdy-Kul (2.2–2.3 billion years) [5] allows us to conclude that the sedimentation of terrigenous material occurred as a result of the erosion of the Earth's crust mainly in the Paleoproterozoic.

This conclusion is partly consistent with the results of U–Pb age dating of detrital zircons from paleoplacers in rocks of the Sharykskaya series [4], since the most ancient of them are of 2.6 billion years. The age of predominant detrital zircons (1.4–1.35 and 1.05–0.95 Ba) allows us to estimate the time of sedimentation as early as ~1.0 Ba; that is, sedimentogenesis occurred in the Neoproterozoic. Xenogenic (detrital) zircon cores with an age of ~2.0 Ba have been found in high-pressure diamond-bearing rocks [6].

These data testify in favor of the Precambrian age of the crust, but do not give an answer to the question about the time of formation of the Kokchetav microcontinent as a stable crustal block. The age of metamorphic zircons from gneisses of the Zerendinskaya series (1150 ± 50 Ma) is the only evidence of the manifestation of an early metamorphism in rocks of the microcontinent basement [7]. The most ancient granites intruded rocks of the Zerendinskaya series, formed 1128 ± 12 million years ago [8].

This study aims to estimate the time of formation of the basement of the Kokchetav microcontinent and identify the role of pre-Paleozoic granitoid magmatism during the evolution of the crust of this structure. Formation of the stable crust of continental blocks is the result of metamorphism and granite formation. Therefore, to estimate the time of formation of the Kokchetav microcontinent basement, the composition and isotopic-geochemical characteristics of gneissogranites of the basement were studied. In addition, their age was defined, which makes it possible to establish the possible geodynamic environment of formation of granitoids and to correlate this complex with magmatic complexes of acid composition of other continental blocks in the Caledonian folded structures in Kazakhstan.

The object of the present investigation is gneissogranites, exposed in the cliffs of the Chaglinskoe water reservoir in the vicinity of the town of Kokchetav.

Structure and Composition of Granitoids

The Kokchetav–Ulutau–North Tien Shan folded zone is divided into a number of ancient blocks or microcontinents: Kokchetav, Ulutausskii, Aktau-Mointinskii, Moyinkum, Iliyskii(?), which are considered as fragments of a large continent. Rocks of the Kokchetav microcontinent basement are represented by biotite gneissogranites and granitogneisses, high-aluminous biotite–garnet–kyanite (±sillimanite), and mica schists.

Gneissogranites exposed on the right shore of the Chaglinskoe water reservoir are intensely deformed and sheeted due to the superimposed retrogressive

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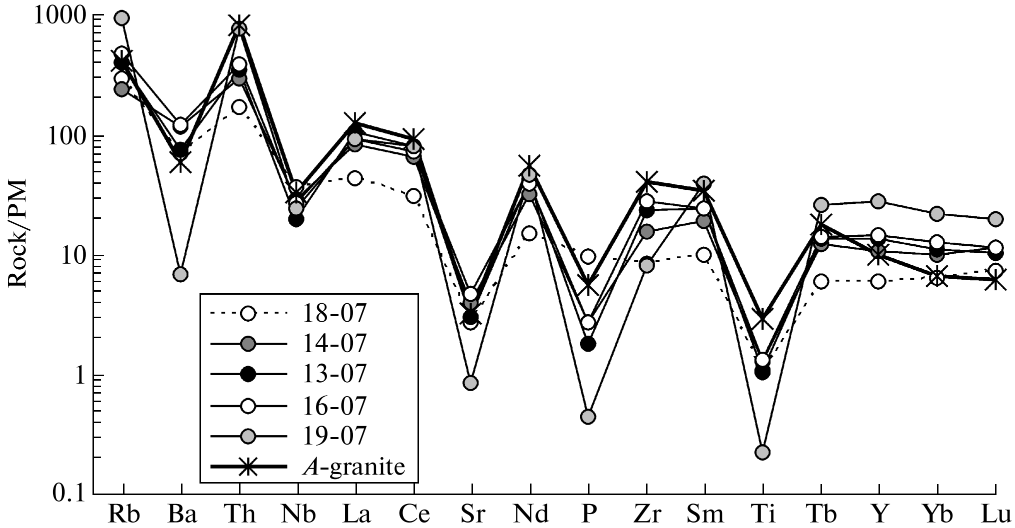

Fig. 1. Multi-element spectra of gneissogranites of the Kokchetav microcontinent. For comparison, the spectrum of A-granites after [9] is shown.

dynamic metamorphism. In some outcrops gneissogranites look like mica schists. Granitoids are injected by weakly deformed feldspathic amphibolite bodies, which are in concordance with the schistosity. The rocks are characterized by hypidiomorphic-to-cataclastic structures and gneissic and roughly-banded textures. Deformations were accompanied by regressive metamorphism that is represented by the development of muscovite and sericite along the schistosity planes. Granitoids are composed of plagioclase, microcline, quartz, and biotite; accessory minerals are zircon and apatite.

According to the content of the basic elements (SiO_2 =73–77 wt. %), the rocks studied correspond predominantly to leucogranite of the normal range of alkalinity with a predominance of potassium over sodium (K_2O/Na_2O =1.5–2.2). Due to the low aluminum and high iron content (FeO*/(FeO* + MgO) = 0.86–0.97, granitoids can be referred to the *A*-type of granites formed under the intraplate and postcollisional extension. This conclusion is confirmed by the high concentrations of highly charged elements, especially Nb (14–26 ppm) and heavy REE and Y. The REE spectra of granitoids are weakly fractioned. They are characterized by a low $(La/Yb)_n$ ratio (4.0–8.8) and distinct Eu minimum (0.02–0.64). On multi-element spectra negative anomalies of Sr, P, and Ti are clearly manifested, while the negative Nb anomaly is poorly expressed. All of this underlines the similarity of granitoids studied with *A*-type granites [9] (Fig. 1). The granites studied have a higher Y/Nb ratio (1.1–7.1) and Yb/Ta ratio(1.0–4.7), which is characteristic for *A*-type granites, resulting from crustal sources [10], whereas differentiates of basic magmas have low Y/Nb and Yb/Ta ratios (less than 1.2), which are closer to the values for oceanic island basalts (~0.6). Paleoproterozoic granitoids are characterized by the Paleoproterozoic estimates of the model Nd age of $T_{Nd}(DM)$ = 2.3–2.4 Ba and low negative ε_{Nd} values (–7.8) for the time of their formation (~1.15 billion years). This indicates that their formation was connected with the melting of the Early Precambrian crust, which is evidently the Kokchetav microcontinent basement.

U–Pb Datings of Zircons

To determine the age of formation of granitoids, the sample was taken from the rocky outcrop on the shore of the Chaglinskoe water reservoir (53°13′44″N, 69°15′20″ E). The age dating was made by U–Pb method (SHRIMP-II) at the Center for Isotope Research of VSEGEI (St. Petersburg). The dating technique and data processing method are described in [11]. Zircons from gneissogranites are presented by brown, clear or translucent prismatic crystals (C_{el}=1.5–2) with a corroded surface and internal cracks that probably resulted from imposed deformations. On the cathodoluminescence image (Fig. 2), zircon is characterized by clearly manifested oscillatory zoning. The character of zoning, contents of U (117–388 g/t) and Th (47–202 g/t), as well as the Th/U ratio (0.4–0.5), are typical of magmatic zircons. The concordant zircon age was calculated on 7 points (1148 ± 16 Ma (MSWD=6. 2)) (Fig. 3).

This value within the error corresponds to the weighed age of 1169 ± 12 Ma, characterized by the low MSWD value (0.34).

The isotopic system of three zircon grains was probably disturbed. Zircons are characterized by younger age values from 440 to 1050 million years, which are not used to estimate the age of zircon (Table 2). Given the magmatic origin of zircon grain dated, the

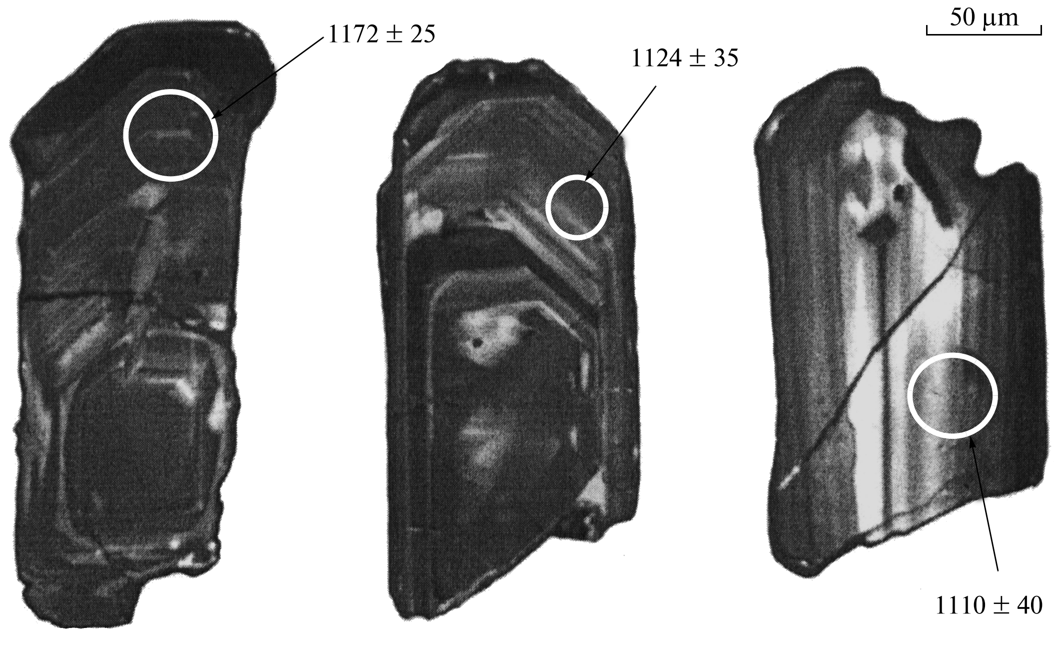

Fig. 2. Cathodoluminescent images of zircons from gneissogranites. The dating points and age estimates (million years) from the $^{207}Pb/^{206}Pb$ are shown.

age of ~1150 Ma was obtained, which corresponds to the time of formation gneissogranites.

DISCUSSION AND CONCLUSIONS

The results of the U–Pb dating suggest that the formation of gneissogranites was associated with Grenvillian orogenic events, and, according to the geochemical characteristics of granitoids, occurred at the stage of postcollisional extension. During previous studies, the Grenvillian age (1128 ± 12 Ma) was established for the granodiorites of small intrusive bodies in the rocks of the Zerendinskaya series (4 km to the northeast of the Borovskoi granite massif) [8]. In total, these geochronological data indicate large-scale manifestations of granitoid magmatism of the Grenvillian phase in the structure of the Kokchetav microcontinent. The Early Proterozoic (~920 million years) acid volcanites and granitoids were found within the Aktau-Mointinskii massif [12]. Similar to the gneissogranites investigated in this work, rhyolites, trahiriolites, and leicogranites correspond geochemically to the A-type granitoids and they are characterized by a Paleoproterozoic model Nd age (T_{Nd}(DM) = 1.73–1.95 billion years). These data suggest a certain similarity of composition and age of the crust of the Kokchetav and Aktau-Mointinskii massifs and their belonging to a single continental block. In this case the formation of the Mezo-Neoproterozoic granitoids and acid volcanites probably reflects the different stages of evolution of the continental crust: the collisional stage (gneissogranites of the Kokchetav microcontinent) and intraplate stage (volcanites and granites of Aktau-Mointinskii massif). This is consistent with the time gap (more than 100 million years) in the formation of rocks. Thus, the formation of the Precambrian continental crust, represented by microcontinents or massifs of the Caledonian structures in Kazakhstan was the result of Mezoproterozoic collision events. Most likely, the continental blocks considered were parts of the Mezoproterozoic Rodinia supercontinent, and their separation is due to the disintegration of Rodinia in the Neoproterozoic.

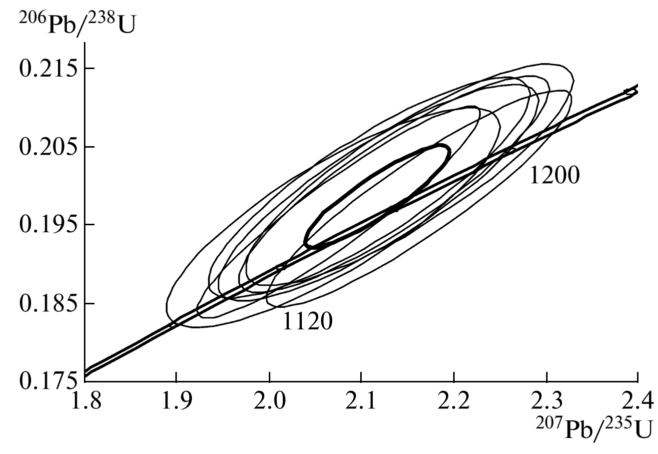

Fig. 3. The Concordia diagram for zircons from gneissogranites (sample 13-07).

Table 1. Content of petrogenic and rare-earth elements and isotope characteristics of representative samples of gneissogranites of the Kokchetav microcontinent

Component, ratio	18-07	14-07	16-07	13-07	21-07	19-07
SiO_2	67.04	73.21	73.86	75.21	76.12	76.61
TiO_2	0.23	0.28	0.29	0.24	0.05	0.05
Al_2O_3	13.11	13.14	12.83	12.62	13.02	13.64
Fe_2O_3	2.86	3.19	4.14	3.31	2.03	1.07
MnO	0.05	0.03	0.04	0.04	0.04	0.01
MgO	0.42	0.21	0.23	0.15	0.06	0.03
CaO	0.77	1.61	1.46	1.35	0.75	0.66
Na_2O	1.65	2.30	2.24	2.22	2.69	2.92
K_2O	3.64	4.85	4.21	4.57	4.57	4.42
P_2O_5	0.21	0.06	0.06	0.04	0.02	0.01
P.p.p.	0.97	1.25	0.84	0.42	0.77	0.67
Total	100.95	100.13	100.20	100.17	100.12	100.09
U	1.3	2.9	1.5	2.0	1.3	3.3
Th	14.5	24.5	21.0	24.7	7.7	46.6
Rb	184	153	304	253	–	589
Ba	485	828	830	520	–	480
Sr	57	84	101	65	–	18
La	29.95	56.42	63	72	–	64
Ce	55.00	114.70	127	142	–	142
Pr	5.40	11.70	14.9	16.1	–	17.9
Nd	20.00	43.43	53	57	–	63
Sm	4.42	8.54	10.8	10.6	–	17
Eu	0.91	1.55	1.29	0.9	–	0.13
Gd	4.10	8.36	9.6	8.8	–	15.1
Tb	0.65	1.34	1.51	1.45	–	2.8
Dy	3.97	7.58	9.5	8.8	–	16.9
Ho	0.89	1.65	1.99	1.88	–	3.6
Er	2.77	4.56	5.8	5.5	–	10.6
Tm	0.44	0.68	0.88	0.88	–	1.69
Yb	3.14	4.98	6.3	5.5	–	10.9
Lu	0.55	0.85	0.85	0.76	–	1.47
Zr	96	172	310	262	–	90
Hf	2.81	5.19	9.1	7.5	–	4.3
Ta	3.18	1.46	1.83	1.17	–	3.6
Nb	25.7	20.4	19.1	13.9	–	17.6
Y	27	49	66	61	–	125
$(La/Yb)_n$	6.4	7.6	6.7	8.8	–	4.0
Eu/Eu*	0.64	0.55	0.38	0.28	–	0.02
Y/Nb	1.1	2.4	3.5	4.4	–	7.1
Yb/Ta	1.0	3.4	3.4	4.7	–	3.0
$^{147}Sm/^{144}Nd$	0.1139	0.1152	–	–	–	–
$^{143}Nd/^{144}Nd$	0.511618 ± 18	0.511626 ± 13	–	–	–	–
ε_{Nd}	–7.8	–7.8	–	–	–	–
T_{Nd}(DM), Ma	2333	2351	–	–	–	–

Note: Dashed line is n/a.

Table 2. U–Pb isotope data for zircons from gneissogranites

Analyzed point	$^{206}Pb_c$, %	U, ppm	Th, ppm	$^{232}Th/^{238}U$	$^{206}Pb^*$, ppm	Age, Ma $^{206}Pb/^{238}U$	Age, Ma $^{207}Pb/^{206}Pb$	*D*, %	(1) $^{238}U/^{206}Pb^*$	±%	(1) $^{207}Pb^*/^{206}Pb^*$	±%	(1) $^{207}Pb^*/^{235}U$	±%	(1) $^{206}Pb^*/^{238}U$	±%	*Rho*
13.1	–	259	94	0.38	44.2	1171 ± 33	1124 ± 35	–4	5.02	2.8	0.0771	1.8	2.119	3.3	0.1993	2.8	0.848
13.2	0.38	99	97	1.01	7.59	553 ± 19	401 ± 110	–27	11.21	3	0.0547	5	0.673	5.9	0.0892	3	0.519
13.3	–	369	136	0.38	62.4	1160 ± 31	1108 ± 22	–4	5.08	2.8	0.0765	1.1	2.076	3	0.1968	2.8	0.931
13.4	0.07	1106	188	0.18	144	902 ± 24	928 ± 16	2	6.6	2.8	0.06999	0.79	1.463	2.9	0.1516	2.8	0.961
13.5	0.13	117	47	0.42	19.7	1157 ± 33	1110 ± 40	–4	5.1	2.9	0.0766	2	2.07	3.6	0.1961	2.9	0.822
13.6	–	305	110	0.37	52.5	1177 ± 32	1129 ± 31	–4	4.99	2.8	0.0773	1.5	2.135	3.2	0.2004	2.8	0.878
13.7	0.39	388	202	0.54	58.8	1050 ± 29	1021 ± 37	–2	5.69	2.8	0.0732	1.8	1.773	3.4	0.1756	2.8	0.838
13.8	–	175	73	0.43	30	1173 ± 33	1108 ± 35	–6	5	2.9	0.0765	1.8	2.109	3.4	0.1999	2.9	0.853
13.9	–	255	122	0.50	44.1	1183 ± 33	1133 ± 35	–4	4.96	2.9	0.0774	1.8	2.152	3.4	0.2015	2.9	0.851
13.10	0.10	295	111	0.39	50.4	1163 ± 32	1172 ± 25	0	5.04	2.8	0.079	1.3	2.163	3.1	0.1985	2.8	0.913

Note: Errors are at the level of 1σ; Pb_c and Pb* are common and radiogenic Pb, respectively. The standard calibration error is 0.70%. (1)–common Pb correction using ^{204}Pb. *D* is discordance; negative values are inverse discordant ages. *Rho* is the correlation coefficient between $^{207}Pb^*/^{235}U$ and $^{206}Pb^*/^{238}U$.

The Sm–Nd isotopic data of gneissogranites confirm the idea of the Early Precambrian age of the crust of the Kokchetav microcontinent basement.

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