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THE JUNCTION ZONE OF THE GORNY ALTAI AND RUDNY ALTAI TERRANES: STRUCTURE AND EVOLUTION

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A composite collage of terranes is located between East Kazakhstan and Gorny Altai, which formed at the Late Devonian-Early Carboniferous and Late Carboniferous-Permian collision stages. These terranes resulted from the oblique collision of the Altai-Mongolian terrane (Gondwana group) with the Siberian continent and from collision of the Kazakhstan and Siberian continents, respectively. The paleomagnetic and structural data indicate the Eifel-Givetian drift of the Altai-Mongolian terrane as part of the Paleoasian oceanic lithosphere. The rate of displacement is more than 2000 km along the paleomeridian. The Emsian rocks of the Altai-Mongolian terrane formed at 1–4° N, and the Emsian rocks of the active margin of the Siberian continent — at 27–30° N. In the late Givetian, the Altai-Mongolian terrane collided with the Siberian continent and started to move along its southern margin. The "oblique" terrane-continent collision resulted in Late Devonian dextral strike-slip faults and the Charysh-Terekta imbricated suture zone. Some tectonic sheets which were detached from the Siberian continent and Altai-Mongolian terranes are fragments of the Late Cambrian-Early Ordovician oceanic crust which formed from 6° S to 14° N. The Middle Carboniferous-Early Permian collision of the Kazakhstan and Siberian continents resulted in sinistral strike-slip faults with the rate of displacement of up to several hundred kilometers in Rudny Altai and Gorny Altai. The high-rate strike-slip faults of different ages and orientations formed the present-day mosaic-block structure of the western Altai-Sayan folded area and East Kazakhstan, which is a collage of terranes having disturbed paleogeographic, paleotectonic, and metallogenic zonation.

Evolution, terrane, collision, strike-slip fault, paleomagnetism, geochemistry, Gorny Altai, Rudny Altai

INTRODUCTION

There is much speculation about Devonian-Early Carboniferous rocks in Eastern Kazakhstan, Rudny Altai, and Gorny Altai, which make up a single lateral series of geodynamic units of an active margin formed over the consolidated Caledonian basement of the Siberian continent [1–3]. In northwestern Gorny Altai, investigators traditionally recognize a Late Riphean-Early Ordovician succession (from bottom to top): Maralikha metasedimentary formation, Zasur'ya volcanosedimentary formation, Charysh terrigenous formation, and Suetka terrigenous formation. The formations are linked by gradual stratigraphic transitions [4, 5]. We give a new interpretation of structural, paleomagnetic, geochemical, and biostratigraphical data obtained while studying the structural zones in Eastern Kazakhstan and western Altai-Sayan area. The results suggest Eifelian-Permian large-amplitude horizontal displacements, which formed a collage of terranes in the regions under investigation. The total displacement of Emsian rocks of the Siberian continent (Salair-Altai zone) and Altai-Mongolian terrane in the Eifelian-Givetian is estimated at more than 2000 km according to paleomagnetic data [6].

We concluded that the sheeted structure of northwestern Gorny Altai (Charysh-Inya and Talitsa structural

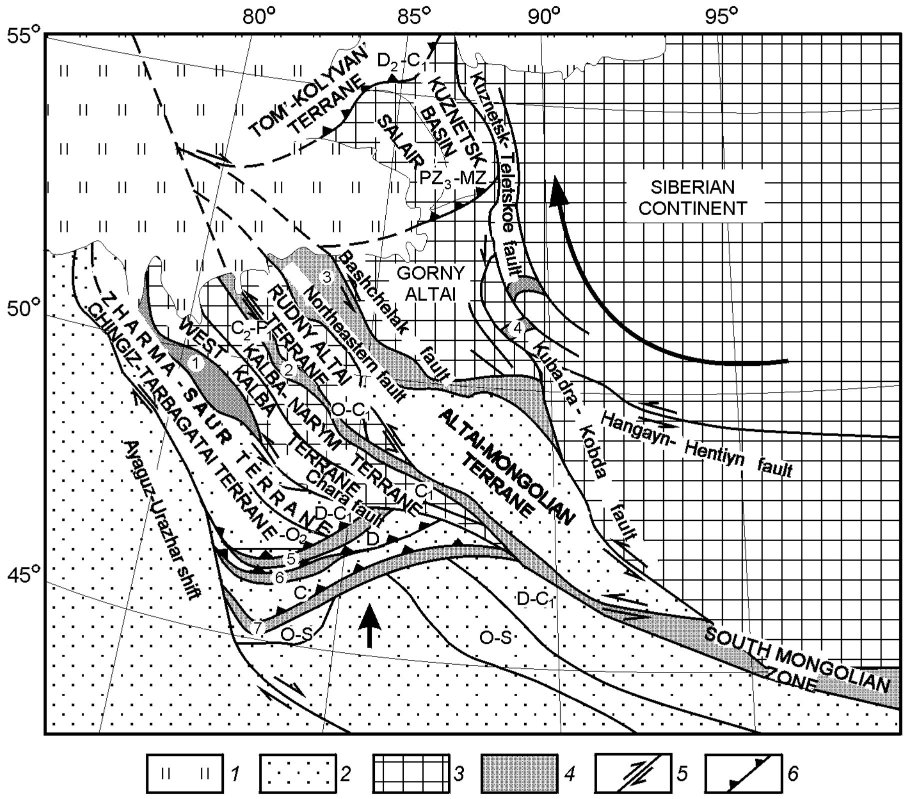

Fig. 1. Schematic Late Paleozoic junction zone of the Siberian and Kazakhstan continents. ***1*** **— Cenozoic sediments of the Biya-Barnaul depression;** ***2*** **— structures of the Kazakhstan continent;** ***3*** **— structures of the Siberian continent;** ***4*** **— reactivated suture zones: 1 — Chara, 2 — Irtysh, 3 — Charysh-Terekta, 4 — Kurai-Ulagan, 5 — Barlik-Khebukesarai-Khongulen, 6 — Mailskaya, 7 — Dalabute;** ***5*** **— strike-slip faults,** ***6*** **— thrusts.**

zones) formed in the Middle-Late Paleozoic. The most interesting entity is the Zasur'ya Formation, whose siliceous rocks contain numerous remnants of Upper Cambrian-Early Ordovician conodonts and Radiolaria [7]. In geochemistry the Zasur'ya volcanic rocks are close to MOR and oceanic-island basalts. Up to the recent time, only fragments of the Late Riphean-Early Cambrian oceanic crust have been known in the whole Altai-Sayan area [3, 8, 9]. The obtained structural, paleontological, geochemical, and paleomagnetic data significantly changed the ideas of the tectonic and geodynamic evolution of the region, which is a collage of terranes. In addition, the new results allowed us to verify the available Devonian-Early Carboniferous geodynamic reconstructions of the Paleo-Asian ocean.

STRUCTURE OF GORNY ALTAI–RUDNY ALTAI JUNCTION ZONE

Northwestern Gorny Altai is composed mainly of the rocks of the WNW-striking Charysh-Terekta suture zone (Fig. 1). The Northeastern crush zone separates this suture zone from the Rudny Altai terrane, cutting its elements at an acute angle. The suture zone is bounded by the Gorny Altai terrane in the northeast and by the Altai-Mongolian terrane in the south [3].

Our interpretation (Fig. 2) is based on original and published structural, geochronological, and paleomagnetic data [6, 10–12]. It considers the Northeastern crush zone and the Bashchelak fault, transecting the Charysh-Terekta suture zone, as sinistral strike-slip faults formed in the Middle Carboniferous-Permian together with the Irtysh crush zone. These faults resulted from the collision of the Siberian and Kazakhstan continents. They reactivated the Late Devonian-Early Carboniferous dextral strike-slip faults: Teletsk, Charysh-Terekta, and others, which formed as a result of the collision of the Altai-Mongolian terrane and the Siberian continent. The ratios of regional strike-slip deformations of different ages and orientation are clearly seen in northwestern Gorny Altai (Fig. 2).

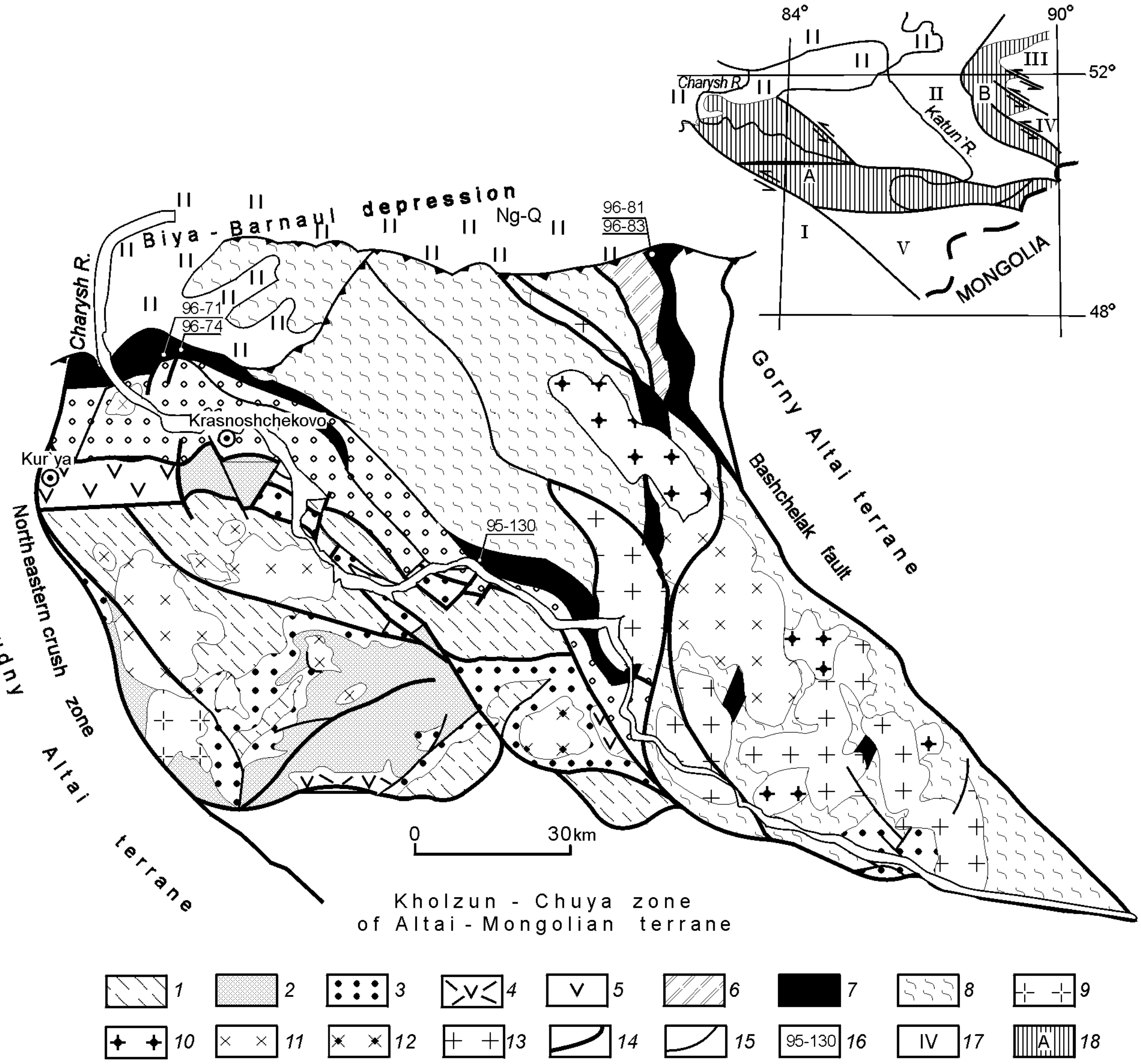

Fig. 2. Schematic geology and structure of northwestern Gorny Altai (compiled after [23]). ***1–8*** **— structural units of the Charysh-Terekta crush zone:** ***1–4*** **— Inya (*1* — Suetka Formation, $\in_{2-3}$; *2* — carbonate rocks, *3* — terrigenous-carbonate rocks, O–S; *4* — volcano-sedimentary rocks, D_{1-2}), *5* — Kur'ya-Akimov (Kukui Formation, D_{1-2}), *6* — Charysh (Charysh and Suetka Formations, O_{1-2}), *7* — Zasur'ya Formation, $\in_{1-2}$– O_1, *8* — Talitsa (Maralikha Formation, Rf_3– $\in_1$); *9* — amphibole-biotite granites, P_2–T_1; *10* — granites and leucogranites, D_3–C_1; *11* — biotite-hornblende granitoids, D_3–C_1; *12* — amphibole-biotite granites, D_2; *13* — gabbro-diorite-granodiorites, D_2; *14* — tectonic boundaries; *15* — stratigraphic boundaries; *16* — sampling locality; *17* — terranes: I — Rudny Altai, II — Gorny Altai, III — West Sayan, IV — Chulyshman, V — Altai-Mongolian; *18* — suture zones: A — Charysh-Terekta, B — Kurai-Ulagan.**

The Inya structural unit consists of sand-shale deposits of the Suetka Formation at the base, which are similar to the Middle-Upper Cambrian flysch of the Kadrin Formation of the Anui-Chuya fore-arc trough [4]. The Suetka Formation is made up of feldspar-quartz rocks and polymictic terrigenous rocks. Greenish-gray and violet-gray polymictic sandstones, green and violet phyllitized shales, and, less often, conglomerates and gravelstones are typical. These deposits have a rhythmical bedding with the rhythm thickness varying from initial to tens of centimeters. The conglomerates and gravelstones consist chiefly of clasts of underlying sandstones and shales and well-rounded pebbles of allochthonous siliceous rocks, quartzites, marblized limestones, granites, granophyres, and porphyrites. The matrix is composed of quartz-albite-chlorite-sericite material. The sandstones consist of albite and quartz fragments. The composition of the clastic material [4] evidences that the sand-shale fragments could have been supplied by an island arc, like that of Gorny Altai, from which the clastic material was delivered to the Anui-Chuya fore-arc trough [13]. Upsection, the Inya unit is composed of Ordovician-Silurian terrigenous-carbonate rocks (Voskresenskaya, Bugryshikha, Khankhara, Palatinskaya, Chagyr, and other formations), which are similar to the units of the Anui-Chuya zone of the same age [1, 14, 15] in lithology, stratigraphy, and fauna complexes.

The Kur'ya-Akimov structural unit is composed of Early-Middle Devonian volcanosedimentary rocks of the Kukui Formation, consisting of basic, intermediate, and, less often, acid volcanic rocks, mottled tuffs, tuff-gravelstones, sandstones, and siltstones. Petrogeochemistry of the volcanic rocks suggests that they erupted in active-margin setting [16].

The Charysh structural unit is composed of rhythmically bedding gray-green sandstones and siltstones and interlayers of coarse-clastic rocks. The upper part of the section consists of rhythmically bedding mottled sandstones, siltstones, siliceous-clayey, and siliceous rocks. The lower part was earlier attributed to the Suetka or undivided Suetka-Charysh Formation, while the upper part, to the Zasur'ya Formation. According to our data, these rocks are an individual lithologostratigraphic unit which formed, probably, in the setting of Middle-Upper Ordovician fore-arc trough. The rhythmically bedding (with rhythm thickness varying from initial centimeters to initial meters) sandstones and siltstones consist of fragments of plagioclase and siliceous rocks. They include lenses and interlayers of gravelstones and conglomerates with dominating rounded fragments of gray, green, violet, and dark-red siliceous rocks and pyroxene-plagioclase porphyrites. The listed siliceous and igneous rocks are analogous to the Late Cambrian-Early Ordovician rocks of the Zasur'ya Formation. The siliceous rocks contain conodonts and radiolaria. Abundant fragments of quartz and albite-quartz porphyries, plagioclase porphyrites, plagiogranites, granites, and diorites are compositionally close to island-arc rocks. As far as the fragments of the Late Cambrian-Early Ordovician rocks of the Zasur'ya Formation occur among conglomerates, which are younger than the Early Ordovician, the fore-arc trough should be younger, too. According to tentative data by K. Iwata, the claret-colored siliceous-clay interbeds of the Charysh Formation contain rich varieties of Middle Ordovician conodonts.

The Zasur'ya structural unit consists of several lenticular tectonic sheets, which are composed of mottled sandstones, gray, green, violet, and dark-red siliceous rocks, pillow-lavas of variolitic, aphyric, plagioclase, and pyroxene-plagioclase basalts, their tuffs, and sills and dikes of gabbros and gabbro-diabases. Dark-red or green layered siliceous rocks contain various conodonts and radiolaria evidencing for Upper Cambrian-Early Ordovician age (late Tremadoc — early Arenig) [7]. Poorly rounded fragments of siliceous-clayey and siliceous rocks, basalts, and tuffs of the Zasur'ya Formation are found in rare interbeds of sandstones.

Geochemical study of the Zasur'ya rocks (Figs. 3–5) showed the presence of 1) oceanic-island varieties — basalt B-95-130, tuff B-96-71, gabbro B-96-74 and 2) mid-oceanic-ridge varieties — basalt B-96-81 and gabbro-diabase B-96-83.

The basalts have experienced greenschist metamorphism and now are pyroxene-plagioclase porphyrites with clinopyroxene and plagioclase porphyric inclusions. The groundmass was replaced by secondary epidote, chlorite, sericite, calcite, and actinolite. Accessory minerals are spinel and magnetite. The gabbros consist of altered plagioclase and amphibole plus chlorite, calcite, and magnetite.

The major-element chemistry allowed us to relate the basaltoids under investigation to the tholeiitic series. Their compositional points fall in the field of basalts (B-95-130), high-Fe tholeiites (B-96-71, B-96-74, and B-96-81), and high-Mg tholeiites (B-96-83) on the Al_2O_3–FeO*+TiO_2–MgO diagram (Fig. 3, *a*) [17] and in the field of MORB (B-96-81 and B-96-83) and oceanic-island basalts (B-96-71, B-96-74, and B-95-130) on the MnO–TiO_2–P_2O_5 discrimination diagram of Mullen (Fig. 3, *b*) [18]. In general, in major-element contents the Zasur'ya basalts are close to the Hawaiian ones [19, 20] but have higher iron and lower magnesium contents.

The K_2O/P_2O_5 value ranges from 0.1 to 4.6 (Table 2), suggesting that either a mantle source was heterogeneous or the lavas were subjected to low-temperature alteration. The second suggestion is preferable, because the samples B-96-71 (tuff) and B-96-81 (metabasalt) having the smallest K_2O/P_2O_5 values — 0.1 and 0.8, respectively — are more altered than the samples B-96-74 (gabbro) (3.9) and B-96-83 (gabbro-diabase) (4.6), which are massive igneous rocks. The first variant cannot be ruled out either, because we suggest two types of basalts: MORB and OIB.

In geochemistry of trace and rare-earth elements, known as the most incompatible elements, the Zasur'ya rocks are intermediate between MORB and OIB. On the Th–Hf/3–Ta discrimination diagram of Wood [21],

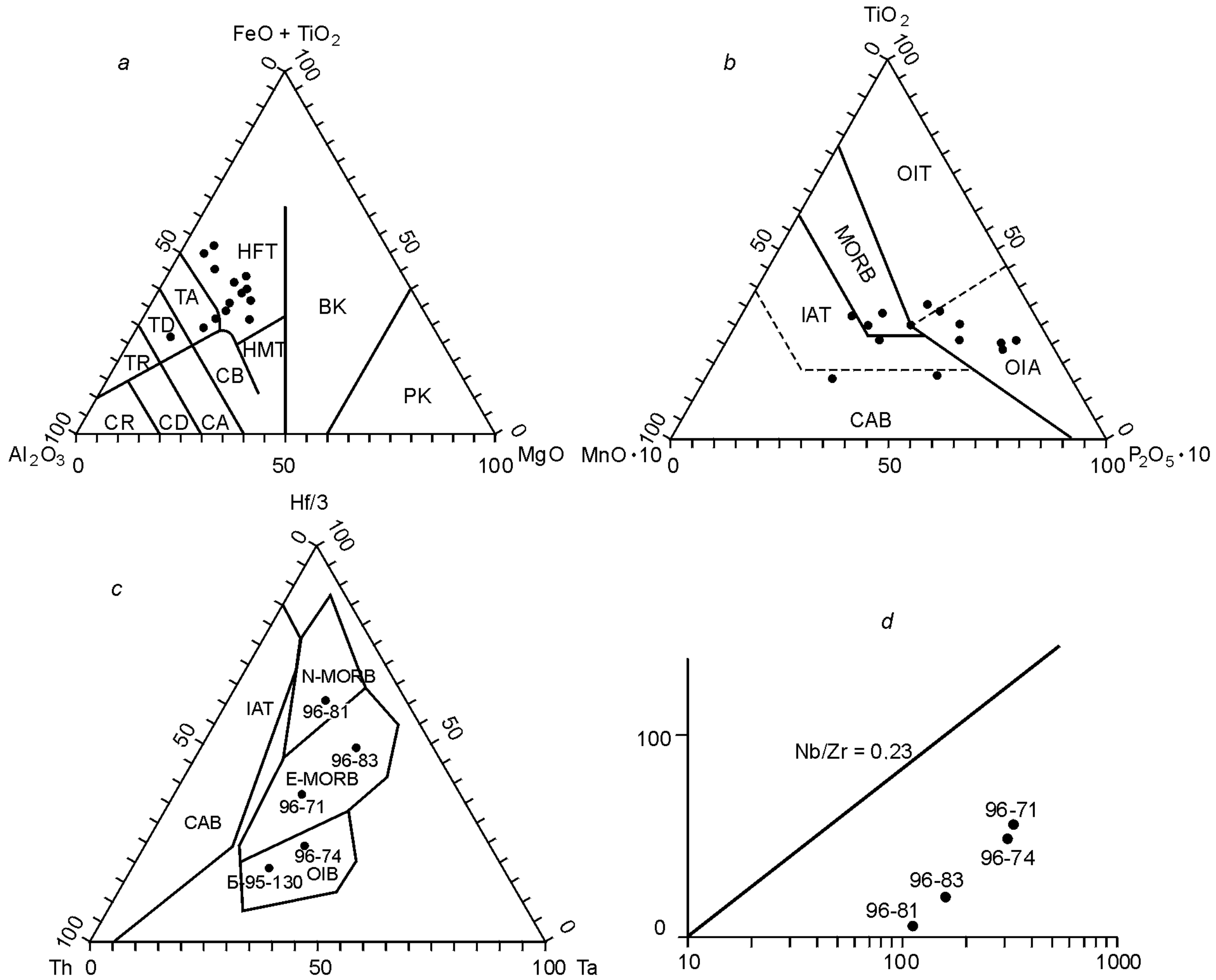

Fig. 3. Chemical composition of Zasur'ya basaltic rocks. ***a*** **— Al_2O_3–FeO+ TiO_2–MgO classification diagram; discrimination diagrams:** ***b*** **— MnO–TiO_2–P_2O_5,** ***c*** **— Th–Hf–Ta,** ***d*** **— Nb/Zr plot. Tholeiitic series: TR — rhyolite, TD — dacite, HFT — high-Fe tholeiite. Calc-alkalic series: CR — rhyolite, CD — dacite, CA — andesite; HMT — high-Mg tholeiite; BK — komatiitic basalt; PK — komatiite; IAT — island-arc tholeiites; MORB — MOR basalts; OIT — ocean-island tholeiites; OIA — oceanic-island alkali basalts; CAB — calc-alkalic basalts; OIB — oceanic-island basalts.**

the composition points fall in the fields of N-MORB (B-96-81), within-plate tholeiites, and E-MORB (B-96-71, B-96-83) and in the transition field between within-plate tholeiites and within-plate alkali basalts (B-96-74, B-95-130) (Fig. 3, *c*).

In the context of rock genesis, Nb/Zr ratio is of special interest. All the samples have a Nb/Zr ratio below 0.23; on the Nb–Zr plot the samples B-96-71, B-96-74, and B-96-81, and B-96-83 form two separate groups (Fig. 3, *d*). This suggests two different sources of basalts. The latter is supported by different Th contents in these samples: 3.7 and 3.5 ppm (B-96-71, B-96-74) and 0.3 and 0.4 ppm (B-96-81, B-96-83) (Table 2).

Figure 4 shows chondrite-normalized spidergrams of trace elements. The patterns were compared with those of the average trace-element contents for normal MORB and oceanic-island basalts [17]. The pattern for B-96-81 is very similar to the average MORB curve, as well as the B-96-83 plot, especially its right end. The B-96-71 plot and the middle and right ends of the B-96-74 plot are similar to the average OIB curve.

The Zasur'ya basalts are characterized by high REE contents, 20–150 times exceeding those in chondrite, and by a negative slope of chondrite-normalized REE patterns reflecting HREE depletion (Fig. 5). The exception is the sample B-96-81, whose REE pattern is nearly parallel to the chondritic line but occurs at level 20. Besides, three groups can be recognized by REE differentiation: 1) La/Yb = 1 for the sample B-96-81

Table 1

Paleomagnetic Directions for Devonian-Carboniferous Rocks from East Kazakhstan and Gorny Altai Terranes

Nos.	Units	Age	N	D_c	I_c	α_{95}	D_a	I_a	α_{95}	Pl
	Altai terrane: active-margin units of the Siberian continent									
1	Kuratin Formation, Kislaya R.: lavas, tuffs, and sediments	D_2gv_1	9	205	69	12	82	41	8	23 N
2	Kuratin Formation, Ursul R.: lavas and sediments	D_2gv_1	7	269	55	11	80	44	10	26 N
3	Taldytyurgun Formation, Sukhoi Tydtugem R.: red sandstones and tuffstones	D_1em	4	61	42	15	86	49	10	30 N
4	Taldytyurgun Formation, Sukhoi Tydtugem R.: tuffstones	D_1em	4	44	59	8.9	88	45	8.9	27 N
	Average for the terrane		24	145	56	12	84	45	9	27 N
	Altai-Mongolian terrane: active margin units									
5	Sebystai Formation, Kyzyl-Shin R.: sandstones	D_1em	18	104	31	—	225	3	8	1 N
6	Sebystai Formation, Kyzyl-Shin R.: sandstones	D_1em	6	52	35	—	221	9	8.7	4 N
7	Ulandryk Formation, Chagan-Burgazy R.: sandstones	D_1em	6	346	10	30	258	4	7	2 N
8	Ulandryk Formation, Chagan-Burgazy R.: sandstones	D_1em	5	10	13	18	204	–9	14	4 N
	Average for the terrane		35	128	22	24	227	3	38	3 N
	Rudny Altai terrane: active-margin units of the Siberian continent									
9	Berezovka Formation, Zmeinogorsk: tuffstones	D_1em	4	174	–41	59	279	46	14	28 N
10	Zavodskoe Formation, Zmeinogorsk: tuffs	D_2gv	5	145	–67	73	244	37	13	21 N
11	Zavodskoe Formation, Zmeinogorsk: tuffs	D_2gv	6	48	–8	53	73	36	22	20 N
	Average for the terrane		15	89	–39	45	259	40	16	23 N
	Zharma-Saur terrane: active-margin units of the Kazakhstan continent									
12	Talovka and Shipunovo Formations	D_2gv-D_3	38	285	–55	7.4	269	–51	4.5	32 N
13	Dzhemenei Formation, Zaisan	D_2gv-D_3fr	47	311	–14	12	310	–47	9	28 N
14	Kensai and Kaigenbulak Formations, Saur Ridge	C_{2-3}	66	340	–55	7	288	–54	4	35 N
	Chingiz-Tarbagatai terrane: active-margin units of the Kazakhstan continent									
15	Kaidaul Formation and others	D_2gv-D_3	58	239	–41	9.4	231	–38	5.2	21 N

Note. Paleomagnetic directions were obtained by component analysis and by crossing of remagnetization circles during *T*-cleaning; *N* — number of sampling localities; *D* — declination; *I* — inclination; m — modern coordinates, a — ancient coordinates; α_{95} — angle of confidence (Fisher's statistics); Pl — average paleolatitude. Numbers: 1–3 and 5 are from [6]; 4, 6–11 are new data obtained at the University of Hokkaido; 12, 15 are from [35; 13, 14 are from [38, 40].

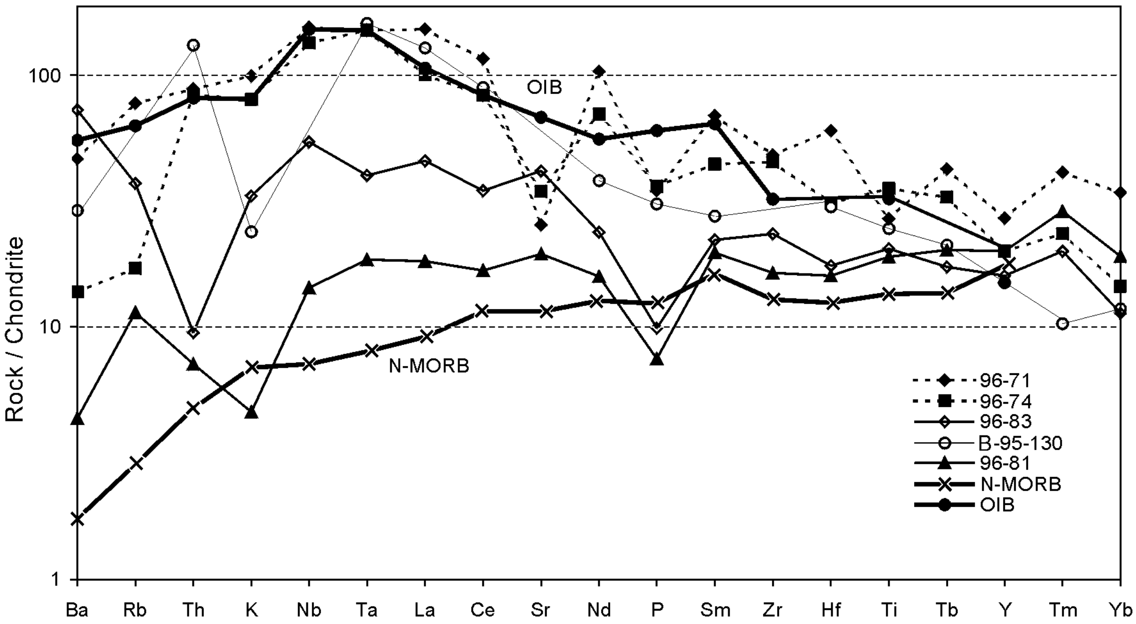

Fig. 4. Chondrite-normalized trace-element concentrations in Zasur'ya rocks. The normalizing values for N-MORB and OIB were taken from [17].

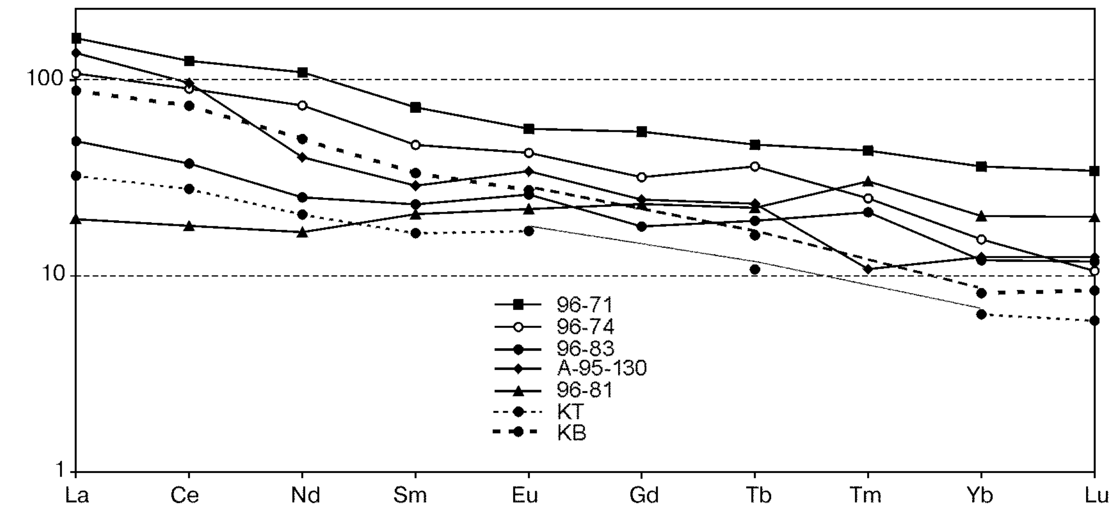

Fig. 5. Chondrite-normalized REE patterns for Zasur'ya rocks. KB — plagioclase-bearing basanite, KT — tholeiitic basalt of Kaula, the Hawaiian system of oceanic islands [19, 20].

(MORB), 2) La/Yb = 6 and 6.6 for B-96-83 and B-96-71, and 3) La/Yb = 11 and 16 for B-96-74 and B-95-130, respectively. Figure 5 shows that the B-96-81 and B-96-83 REE patterns differ from the B-96-71, B-96-74, and B-96-130 REE patterns in contents and degree of differentiation of REE. Comparison of the REE patterns of Zasur'ya rocks and Honolulu and Kaula basalts (Hawaiian system) [19, 20] shows that they are similar in shape and REE contents.

Thus, two types of Zasur'ya basaltoids are distinguished according to their geochemistry: MORB and oceanic-island basalts. According to tentative paleomagnetic data (Table 1), the interlayers of OIB tuffs were formed in the Late Cambrian-Early Ordovician within the band 6° S–14° N.

The Talitsa structural unit consists of dark-gray phyllitized clay and siliceous-clay shales and gray and

Table 2

Contents of Major (%) and Trace Elements (ppm) in Zasur'ya Rocks

Nos.	Component	96-72	97-120-1	97-120-3	97-120-5	B-96-81	B-96-83	B-96-71	B-95-130	96-S-3	96-86-20	B-96-74	KB	KT
1	SiO_2	53.08	51.54	46.36	47.60	48.15	48.26	49.83	49.32	51.96	51.69		47.48	48.75
2	TiO_2	2.75	1.39	4.27	2.89	1.96	2.12	2.78	2.54	0.52	1.18		2.17	1.63
3	Al_2O_3	14.90	14.47	17.54	15.86	13.78	14.92	14.30	19.93	20.82	15.38		14.97	15.46
4	FeO*	14.02	9.18	13.95	12.31	13.96	11.63	15.42	8.14	8.25	8.40		10.45	12.39
5	MnO	0.14	0.21	0.28	0.19	0.26	0.22	0.08	0.12	0.18	0.22		0.16	0.12
6	MgO	2.00	8.80	4.27	8.00	6.99	8.91	2.53	5.85	3.04	5.36		8.76	5.53
7	CaO	4.31	10.18	7.63	8.41	10.91	8.52	4.77	9.35	10.96	13.49		10.14	11.77
8	Na_2O	3.19	2.59	3.39	2.59	2.14	2.96	4.97	3.03	3.18	2.44		3.77	2.45
9	K_2O	3.29	0.43	0.23	0.37	0.13	0.96	2.86	0.69	0.08	0.52		1.05	0.46
10	P_2O_5	0.76	0.19	0.51	0.39	0.16	0.21	0.73	0.65	0.09	0.37		0.63	0.45
11	La					6	15	50	42			33	27.1	10
12	Ce					14.5	30	100	77			72	59	22.3
13	Nd					10	15	65	24			44	29.7	12.3
14	Sm					4	4.5	14	5.6			9	6.48	3.21
15	Eu					1.6	1.9	4.1	2.5			3.1	2	1.24
16	Gd					6	4.6	14	6.3			8.2	—	—
17	Tb					1.05	0.9	2.2	1.1			1.7	0.76	0.51
18	Tm					0.98	0.68	1.4	0.35			0.8	—	—
19	Yb					4.2	2.5	7.5	2.6			3.2	1.7	1.33
20	Lu					0.64	0.38	1.1	0.40			0.34	0.27	0.19
21	Ba					30	500	320	200			95	513	169
22	Rb					4	13	27	—			6	21.3	4.8
23	Th					0.30	0.40	3.70	5.5			3.50	2	1
24	Nb					5	19	54	—			47	31.6	14.3
25	Ta					0.37	0.80	3	3.2			3	1.7	0.65
26	Sr					230	490	300	—			408	938	330
27	Zr					112	160	330	—			310	136	95
28	Hf					3.2	3.5	12	6			6.2	2.9	2.2
29	Y					40	32	54	—			40	21	15

Note. For comparison, compositions of basanite (KB) and tholeiite (KT) of Kaula (Hawaiian system of oceanic islands) are given. Analyses for major elements were performed by the X-ray fluorescence method at the UIGGM, Novosibirsk. Analyses for trace elements were carried out by the neutron-activation method at the UIGGM.

greenish-gray sandstones. The sandstones and shales are often rhythmically interbedded. The shales are represented by chlorite-quartz, sericite-chlorite-quartz, and sericite-chlorite varieties. The sandstones consist of semirounded fragments of quartz, feldspar, sphene, epidote, apatite, as well as microquartzites, siliceous rocks, and porphyrites, and have a siliceous, chlorite-siliceous, or sericite-chlorite-siliceous matrix.

Compositionally similar varieties make up the Gorny Altai series [4] in the Kholzun-Chuya zone of the Altai-Mongolian terrane.

Strongly foliated and plicated rocks in the greenschist facies of metamorphism and isofolded and segmented layers mark the zones of shear deformations related to the Charysh-Terekta strike-slip fault. These zones are specified by the presence of quartz-chlorite-sericite schists and quartz veins up to 5–6 m thick.

Strike-slip deformation zones up to several kilometers wide occur near the boundaries of tectonic units. For example, the crush zone near Ust'-Pustynka Village, along the Charysh cliffs, is over 3 km wide. It is composed of vertically arranged schists over terrigenous rocks of the Suetka Formation, volcanogenic-siliceous rocks of the Zasur'ya Formation, and Ordovician-Silurian carbonate rocks. There, the Suetka Formation is dominated by greenschists. The Zasur'ya Formation consists of tectonic lenses of siliceous-clay shales, cherts, basalts, and quartz-chlorite-sericite schists formed after sandstones and siltstones of the Suetka Formation.

The Zasur'ya and Talitsa tectonic units are everywhere bounded by a melange-greenschist zone 2–3 km thick. This zone includes lenticular blocks of the Zasur'ya igneous and siliceous rocks surrounded by the dynamoschists which formed after the terrigenous rocks of the Maralikha and Charysh Formation.

A typical section of the Zasur'ya Formation in the Molchanikha River basin (15 km NNE of Krasnoshchekovo Village) is considered in detail below. We suggest that the Maralikha Formation is stratigraphically overlain by the Zasur'ya Formation and the latter, by the Charysh Formation. According to our data, there is a thick strike-slip zone. It consists of sand-clayey rocks of the Charysh Formation, red and green cherts of the Zasur'ya Formation, and sand-shaly rocks of the Maralikha Formation. On the left bank of the Molchanikha River, north of the Berezovka River mouth, the section of the strike-slip zone includes the following units (upstream):

1) A member of interbedding gray massive sandstones, thin-bedded green and gray siltstones, and claret-colored siliceous-clayey rocks. Sandstone beds reach several meters in thickness and are strongly segmented into boudins. The siltstones are commonly replaced by phyllitic schists. The dip of beds is 75–80°, the azimuth of dip is 90°. The visible thickness is more than 100 m.

2) A member of rhythmically intercalating thin-bedded green, gray, and claret sandstones, siltstones and siliceous-clayey rocks. SN-striking cleavage is typical. The dip of the layers is 76°, the azimuth of dip is 125°. The visible thickness ranges from 150 to 180 m.

3) A melange zone consisting of angular and oval fragments of red cherts up to several meters long and small fragments of claret-colored siliceous-clayey rocks in a foliated matrix formed after sand-siltstone rocks. The azimuth of strike is 65°. The visible thickness is 25–30 m.

4) A member of siliceous rocks making up the Zasur'ya tectonic sheet. Dark-red cherts (dip angle 40–60°, dip azimuth 90–110°) are separated by thin beds of green siliceous-clayey rocks. In the north, the siliceous rocks are bounded by a near-vertical fault with a strike azimuth of 60°. Numerous small-rate dextral displacements occur parallel to the fault plane. The dextral mode of displacement is evidenced by S-like folds and specific geometry of sliding folds in siliceous rocks at their contact with the fault plane. The thickness of the tectonic sheets ranges from 60 to 80 m.

5) Interbedding sandstones and siltstones of the Charysh Formation. At the contact with the upper siliceous sheet, the rocks are transformed into plicated chlorite schists including sandstone boudins. The thickness of this zone is 0.8–1.0 m. To the north, the chlorite schists are changed by foliated rocks — phyllites and strongly segmented sandstone beds. The internal layering in boudins is turned through 30–40° clockwise with respect to the foliation plane. In addition, the Charysh Formation rocks are characterized by a clear rhomboidal cleavage. All the above features evidence the dextral mode of displacements. The visible thickness of the Charysh Formation is more than 300 m.

The Maralikha Formation, which is a strongly dislocated sand-shale unit, is exposed upstream of the Molchanikha River. The total section along the Molchanikha River demonstrates a dextral strike-slip zone (strike azimuth 60–80°), which is marked by melange zones, foliation zones, and near-fault plicated folds.

The Talitsa structural unit consists of two large sheets separated by a zone of dynamoschists. This zone is composed of quartz-chlorite-sericite schists with chain-aligned lenses of marbleized limestones. The lenses reach several hundred meters in length and tens of meters in thickness. The limestones contain deformed fossils — Early Devonian *Crinoidea* and corals [22].

The age of deformations and faulting in northwestern Gorny Altai (Fig. 2) can be estimated from their relationship with the intrusive bodies, whose age was reported in [23]. The Charysh-Terekta sheeted dextral strike-slip fault zone is intruded by Talitsa granites of late Devonian-early Carboniferous age. Both, the fault zone and granite pluton, are broken by Middle Carboniferous-Early Permian sinistral strike-slip faults of the Northeastern and Bashchelak crush zones. Late Permian-Early Triassic igneous bodies intrude into the crush zones and their adjacent terranes, e.g., the Savvushin pluton and its satellite Volch'i Shkili intrude the Rudny Altai terrane, the Sinyuishin pluton breaks through the Altai-Salair terrane, and the Tigerets and Korovikhin plutons, through the Altai-Mongolian terrane. In the Triassic-Jurassic, the terrane structure was reactivated by strike-slip faults, locally cutting Late Permian-Early Triassic plutons and other intrusive bodies.

DESCRIPTION OF TERRANES

The northwestern Gorny Altai area is located in the junction zone of the Altai-Mongolian, Gorny Altai and Rudny Altai terranes (see Figs. 1 and 2).

It is assumed that **the Altai-Mongolian terrane** (microcontinent) [24] was detached from the North Chinese continent in the Late Riphean. The terrane is composed of shelf and continental-slope terrigenous rocks. More evidence for its relation to the Gondwana group was reported in [3, 25]. At present, the terrane is about 1000 km long and 250 km wide, extending into southern Gorny Altai, Rudny Altai, Western Mongolia, and Chinese Altai. In Rudny Altai and Gorny Altai, it is bounded by the Northeastern and Charysh-Terekta strike-slip zones. The terrane is dominated by Vendian-Early Cambrian rhythmically layered quartz-feldspathic and polymictic sandstones, siliceous shales, and phyllitized clay shales. In Gorny Altai and Western Mongolia, these sequences are considered a 6 km thick Middle Cambrian-Early Ordovician flyschoid sequence [4, 26, 27]. Dergunov et al. [27] showed that the upper flysch horizons contain violet and red sediments and rare interbeds of acid tuffs and clay-siliceous sediments. The flysch varieties are isoclinally folded and transgressively overlain by various Ordovician-Devonian units indicating a complex geodynamic evolution of the Altai-Mongolian terrane. In southern Gorny Altai, the Middle Ordovician gray marine sediments (Kabin and Biryuksa Formations) overlie deformed and metamorphosed basement rocks through basal conglomerates. Upper Ordovician-Lower Silurian gray marine sediments are found in Gorny Altai and Western Mongolia [26, 27]. The Emsian active-margin units (Korgon and Kholzun zones in Gorny Altai) [16, 22, 27] are widely distributed in Western Mongolia. The Emsian units transgressively overlap the Vendian-Early Cambrian and Ordovician-Silurian rocks of the Altai-Mongolian terrane.

The Altai-Mongolian terrane is intruded by Late Devonian-Early Carboniferous granitoids [23]. The latter seem to mark the extension zones related to strike-slip deformations, which occurred along the terrane-Siberian continent collisional boundary.

According to [6] and new paleomagnetic data (Table 1) obtained in laboratories of the UIGGM, at Hokkaido University, and at the Institute of Earth’s Physics, Emsian rocks of the Altai-Mongolian terrane (Sebystai and Ulandryk Formations) formed near the equator — at 1–4° N. The 56° difference in declination of the Ulandryk sequences indicates their rotation relative to each other (Table 1, nos. 7 and 8).

The Gorny Altai terrane consists of many geodynamic units formed near the Siberian continental margin [1, 10, 16, 29–31]. We recognized a Late Vendian-Cambrian island-arc system there, which consists of the rocks of Late Vendian primitive island arc, Late Vendian-Early Cambrian accretionary wedge, Cambrian normal island arc, and its fore-arc and back-arc basins. Late Vendian-Cambrian island-arc margin units are overlain by Ordovician-Early Devonian passive-margin terrigenous-carbonate sediments [1]. In the Emsian-Early Givetian, the geodynamic regime in the region changed, and an active margin formed. Gabbro-diabase dikes and sills [1] and granite bodies [23] are widespread within the terrane. They could have formed under extension related to strike-slip faulting along the Siberian continent margin.

Emsian active-margin units of (Taldytyurgun sandstones and tuffs) and Early Givetian ones (Kuratin lavas, tuffs, and sediments) formed at 27–30° N and 23–26° N, respectively.

The Rudny Altai terrane is composed of volcanosedimentary units of Ordovician-Silurian(?) oceanic crust [22, 32] at the base. The rocks are in the greenschist facies of metamorphism and are compositionally divided into two groups. The oldest are basaltic metaschists, which are overlain by a facies-variable sequence consisting of ortho- and paraschists. The oceanic crust is conformly overlain by a sequence of weakly metamorphosed sandstones and schists (Korbalikha Formation). It was dated at the Early Devonian (Lochkovian-Pragian stage) by the findings of phytoplankton and spores [22], which are interpreted as deep-trench sediments [32].

Upsection, there is a thick unit of Devonian-Carboniferous rocks. Emsian-Early Givetian terrigenous rocks and reef limestones were, probably, accumulated on the slope of a fore-arc trough. They contain interbeds of tuffs, polymictic sandstones, and conglomerates. Their clastic material includes red, violet, gray, black, and green siliceous rocks, volcanic rocks of variable composition, and granitoids, which are missing from the basement of the Devonian section of Rudny Altai. In the set of Emsian fauna and facies composition [1] the deposits of the Rudny Altai terrane are close to those of Salair. In the Late Givetian-Late Devonian, volcanic and plutonic island-arc rocks formed in Rudny Altai, and back-arc basin rocks, in Salair and Gorny Altai [1].

Tentative paleomagnetic data (Table 1) on the Devonian section near the town of Zmeinogorsk show that the Emsian sandstones and siltstones of the Berezovka Formation accumulated at 28° N and the Givetian tuffs of the Zavodskoe Formation at 20° N. Reverse magnetization of the Zavodskoe tuffs (Table 1, no. 11) can be explained by their formation in an epoch of reverse polarity. This is indirectly confirmed by the fact that magnetic declination changed by 180° at points 10 and 11. Our data agree with the data obtained by

Burtman et al. [33] showing that the Rudny Altai active margin had a NE strike in the Middle-Late Devonian but was located at 31.7± 4.1° N.

In the west, the Irtysh crush zone separates the Rudny Altai terrane from the Kalba-Narym and West Kalba terranes, composed mainly of Late Devonian-Early Carboniferous units of fore-arc trough and accretionary wedge [1, 2]. The Rudny Altai, Kalba-Narym, and West Kalba terranes are fragments of a single active margin of the Siberian continent. They were offset many hundreds of kilometers relative to each other along strike-slip faults as a result of the Middle Carboniferous-Permian collision of the Kazakhstan and Siberian continents. The thickness of metamorphic units indicates a 1000 m strike-slip offset for the Irtysh crush zone [34]. In turn, the Chara ophiolitic suture separates the above terranes from the Devonian-Early Carboniferous rocks of the Chingiz-Tarbagatai terrane entering the Kazakhstan continent. Paleomagnetic data show that the Middle-Late Devonian volcanosedimentary rocks of this terrane formed at 21° N and had an EW strike. Thus, the Chingiz-Tarbagatai and Rudny Altai island arcs traveled around 650–1650 km before they met [33]. This value defines the total rate of sinistral strike-slip displacement along the Chara and Irtysh zones.

Paleomagnetic studies of the rocks of the Early-Middle Devonian volcanic belt in Central Kazakhstan showed that it formed at 21–24° N [35]. The northern and northeastern segments of the belt had a SN strike in the ancient system of coordinates, and the southwestern segment, an EW strike. According to our data, the Emsian volcanic belt of the Altai-Mongolian terrane formed at 1–4° N and had a nearly NS strike.

DISCUSSION

The obtained data indicate Late Paleozoic large-scale strike-slip displacements, which were responsible for the formation of the present-day mosaic-block structure of orogenic areas in the Altai-Sayan region and Eastern Kazakhstan. The rocks of the Late Cambrian-Early Ordovician oceanic crust and Ordovician fore-arc trough are possibly fragments of an accretion zone formed on the margin of the Altai-Mongolian terrane. "Oblique" collision of the Altai-Mongolian terrane and Siberian continent and then collision of the Kazakhstan and Siberian continents led to a deformation of the accretion zone. The latter was first split into several tectonic sheets and then broken by transverse strike-slip faults.

Our tentative paleomagnetic and structural data allow conclusions about the scale and direction of strike-slip displacements resulted from the collision of the Altai-Mongolian terrane and Siberian continent (Frasnian-Early Carboniferous) and then from the collision of the Kazakhstan and Siberian continents (Middle Carboniferous-Permian). Paleomagnetic and geochronological data show that the Emsian rocks of the Altai-Mongolian terrane migrated over a distance of more than 2000 km before they were accreted to the Gorny Altai terrane. In the Emsian, the Salair-Altai active margin of the Siberian continent had an EW strike (Fig. 6, *a*) and bounded the latter on the south, at 23–30° N. In the Emsian-Givetian volcanosedimentary rocks of Rudny Altai (21–28° N) were located near the Salair-Altai zone (23–30° N), probably, forming a single EW-striking volcanic belt. In the Devonian-Carboniferous, the Siberian continent and the Devonian active margin rotated clockwise with a speed of up to 2° per 1 Ma [36]. In the Eifelian, the Altai-Mongolian terrane drifted northward, starting from 1–4° N, together with the Paleoasian oceanic lithosphere, which subsided beneath the Siberian continent. At the end of the Middle Devonian the Altai-Mongolian terrane migrated closer to the Siberian continent, and its active margin had NE strike and was located at 31.7± 4.1° N (like the Rudny Altai zone) [33]. The collision of the Altai-Mongolian terrane and Siberian continent led to the formation of dextral strike-slip fault zones: Charysh-Terekta, Kuznetsk-Kurai, and Teletsk fault. The above geological and geochronological data show that the strongest strike-slip deformations in the Charysh-Terekta fault zone occurred in the Late Devonian. In the Teletsk fault zone, strike-slip displacements are recorded by crush zones formed mainly by Early Carboniferous rocks [37]. Thus, in the Devonian-Early Carboniferous, strike-slip deformations separated the marginal part of the Siberian continent into several terranes.

Paleomagnetic, compositional, and structural data on the Charysh-Terekta strike-slip fault zone indicate a complex scenario of the interaction of the Altai-Mongolian terrane with the Siberian continent. After the terrane had collided with the continent in the Late Devonian, it continued to slip along the continental margin before it met the Rudny Altai island arc. That movement agrees well with the general migration of the Paleoasian oceanic lithosphere and Kazakhstan continent westward, toward the East European continent (ancient coordinates) [36]. The later collision of the Kazakhstan and Siberian continents complicated the existing structure (Fig. 6, *b*). This mechanism explains a 2000 km gap between the paleolatitudes of the Emsian rocks of the Anui-Chuya zone in Gorny Altai and those of the Altai-Mongolian terrane.

Based on our own and published paleomagnetic and structural data [1, 2, 6, 33–40], we suggest the

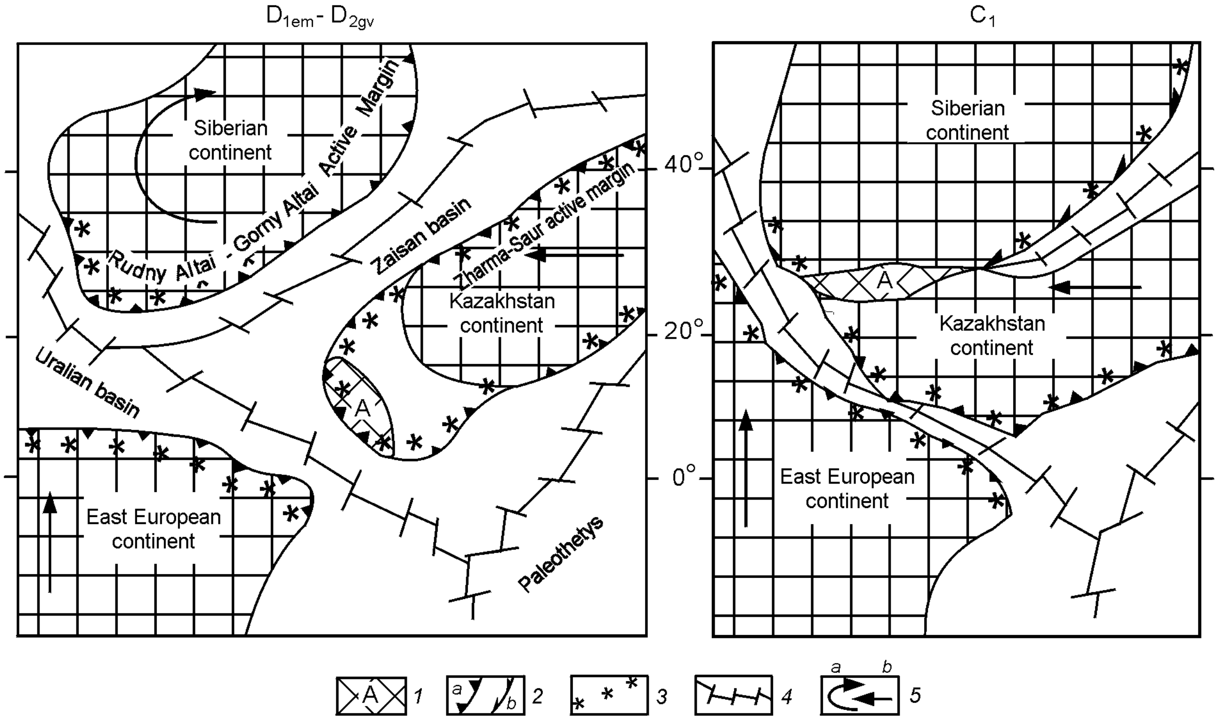

Fig. 6. Geodynamic reconstructions of the Paleo-Asian ocean: *a* — Early-Middle Devonian, *b* — Early Carboniferous (compiled by geological and paleomagnetic data and paleoreconstructions from [6, 31, 33–40]). *1* — Altai-Mongolian (A) terrane of the Gondwana group, *2* — zones of frontal (*a*) and oblique (*b*) subduction; *3* — volcanic belts of active margins (AO); *4* — zones of spreading; *5* — directions of migration of continents: *a* — rotation, *b* — translation.

following paleoreconstructions for the Emsian-Early Givetian and Early Carboniferous stages of the Paleoasian ocean evolution (Fig. 6).

The Emsian-Givetian stage. The Gorny Altai and Rudny Altai volcanic belts were located in a band from 21 to 30° N, close to the southern and southeastern margins of the Siberian continent. The Altai-Mongolian terrane was located near the equator at 1–4° N. At the end of the Middle Devonian, the Altai-Mongolian terrane approached 21–30° N and collided with the Siberian continent. As a result of the subduction of the Ob'-Zaisan oceanic crust, the terrane started to slip along the EW-striking margin of the Siberian continent. This led to the formation of a sheeted suture structure of the Charysh-Terekta zone.

The Early-Middle Carboniferous stage. In the Early Carboniferous, the Altai-Mongolian terrane was driven into between the Gorny Altai and Rudny Altai zones. The Kazakhstan continent bounded by an active margin migrated northeastward (28° N in D_2^2– D_3^1 and 35° N in C_{2-3}) (Table 1) before it collided with the Siberian continent rotating clockwise. In the Middle Carboniferous, the Ob'-Zaisan basin closed, and collision of continents started. This led to formation of the Middle Carboniferous-Permian system of sinistral strike-slip faults in Eastern Kazakhstan, Rudny Altai, and Gorny Altai (Chara, Irtysh and Northeastern faults) and reactivation of the Charysh-Terekta, Kuznetsk-Kurai, and other faults. The rate of displacement along the strike-slip faults is estimated at many hundreds of kilometers. The collision was followed by the formation of Middle-Late Carboniferous molasses and andesite-dacitic, trachyandesitic and trachydacitic volcanic rocks [3, 41, 42].

CONCLUSIONS

A complex structure, which formed in the junction zone between Rudny Altai and Gorny Altai, recorded two important events: Late Devonian collision of the Altai-Mongolian terrane and Siberian continent and Middle Carboniferous-Permian collision of the Kazakhstan and Siberian continents. Paleomagnetic and structural data identified the Eifelian-Givetian drift and Late Devonian slipping of the Altai-Mongolian continent along the southern margin of the Siberian continent, which led to the formation of the sheeted Charysh-Terekta zone in its frontal part. The tectonic sheets are fragments detached from the Siberian continent and Altai-Mongolian terrane and those of the Late Cambrian-Early Ordovician oceanic crust and Middle Ordovician fore-arc trough. According to paleomagnetic data, the Altai-Mongolian terrane migrated over a distance of more than 2000 km.

The Middle Carboniferous-Early Permian collision of the Kazakhstan and Siberian continents resulted in sinistral displacements with a rate of many hundreds of kilometers. Thus, the present-day mosaic-block structure of Eastern Kazakhstan and Gorny Altai is the result of two large collisional events. It is a collage of terranes with disturbed paleogeographic and paleotectonic zonation.

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