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Lithological Markers and Bio-indicators of Deep-water Environments During Paleozoic Siliceous Sedimentation (Gorny Altai Segment of the Paleo-Asian Ocean)

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Abstract

Upper Cambrian–Lower Ordovician volcanic-siliceous-terrigenous strata of the Zasur'ya Group belonging to the Gorny Altai segment of the Paleo-Asian Ocean are considered in this paper. The Gorny Altai segment developed over a long period, of not less than 25–30 million years. The Zasur'ya Group consists of the Listvenny, Talitsa and Marcheta Formations, in ascending stratigraphic order. The Listvenny Formation is represented by basalts, cherts and terrigenous rocks, whereas the Talitsa Formation mainly consists of terrigenous rocks. The Marcheta Formation is characterised by terrigenous rocks, tuffs, cherts and jasperoids. Geochemical features of basalts and tuffs from the Zasur'ya Group indicate they are oceanic island alkali basalts and E-MORB basalts. Lithologic markers of environments of sedimentation within the Gorny Altai segment of the Paleo-Asian Ocean are described, and bio-indicators of the environments of siliceous sedimentation are evaluated. The results indicate that the Zasur'ya Group was deposited in a deep-water oceanic environment.

Key words: Paleo-Asian Ocean, Paleozoic, geochemistry, sedimentology, fauna.

Introduction

Evidence of the oceanic genesis of basalts, siliceous sediments and terrigenous sediments of the Lower Paleozoic Zasur'ya Group, Gorny Altai (see Fig. 1) was first obtained in the mid-1990s (Iwata et al., 1997). The age of these strata was determined as Late Cambrian-Early Ordovician (transitional from Tremadoc to Arenig) on the basis of sporadic finds of organic remains including conodonts, radiolarians and siliceous sponges. Previously, all known Paleozoic volcanic-terrigenous strata from southern West Siberia, Gorny Altai and Salair had been considered to represent volcanic arcs, back-arc structures, and continental volcanics formed at the continental margin of the Siberian Craton. The Zasur'ya Group was identified as a volcanic-sedimentary sequence of the Paleo-Asian Ocean (Berzin et al., 1994), specifically of the Gorny Altai segment (Buslov et al., 2001; Sennikov et al., 2003).

Geochemistry of the Oceanic Rocks

Some geochemical analyses of basalts, gabbros and tuffs from four sections of the Zasur'ya Group have been published previously (Buslov et al., 1999, 2000, 2001; Sennikov et al., 2003). Magma types recognized in that previous work include oceanic island basalts, N-MORB and arc-tholeiites. Additional geochemical data have now been obtained for basalts, tuffs and jasperoids (hydrothermal sediments) from five new localities in three sampled sections of the Zasur'ya Group (Table 1, Figs. 2-6). On the concentration of major elements, the Zasur'ya Group basaltoids possess chemical characteristics (Table1, Fig. 2) of tholeiitic series – high-magnesium tholeiite (C-997, C-9914A), high-ferruginous tholeiite (C-9912) and calc-alkali series – basalt (C-007-3) (Al_2O_3–FeO*+TiO_2–MgO classification diagram). In TiO_2–MnO*10–P_2O_5*10 discrimination diagram by Mullen

Table 1. Rock-forming (wt%) and rare-earth (ppm) element contents of Zasur'ya Group rocks, Gorny Altai.

Compo nent	C-997 basalt	C-9912 basalt	C-9914 A basalt	C-002-6 jasperoid	C-002-17 tuff	C-00-2-24 tuff	C-006 jasperoid	C-007-3 basalt	Kaul basanites (KB)	Kaul tholeiites (KT)	Hydro-thermal solution (East Pacific Uplift-EPU)	Hydro-thermal breccia (Atlantic MORB-HdMdAt
SiO_2	47. 59	46.17	47.96	81.67	56.97	65.09	91.84	47.7	47.48	48.75	0.1	N / a
TiO_2	1.47	2.08	1.539	0.03	0.972	0.712	0.04	2.142	2.17	1.63	N / a	N / a
Al_2O_3	14.45	14.33	15.72	0.82	16.99	13.53	1.46	17.17	14.97	15.46	(Al) 0.013	N / a
FeO	N / a	N / a	N / a	N / a	N / a	N / a	N / a	N / a	6.56	3.4	(Fe) 0.0089	N / a
Fe_2O_3*	12.68	13.99	11.6	16.09	8.01	7.27	5.59	9.47	4.12	9.67	N / a	N / a
MnO	0.225	0.255	0.262	0.03	0.137	0.104	0.03	0.211	0.16	0.12	(Mn) 0.0046	N / a
MgO	8.5	7.48	7.02	0.35	2.93	2.63	0.31	5.74	8.76	5.53	N / a	N / a
CaO	8.8	8.56	8	0.11	4.42	3.66	0.07	7.92	10.14	11.77	(Ca) 60	N / a
Na_2O	2.56	3.81	4.74	0.3	3.98	1.56	0.3	3.2	3.77	2.45	(Na) 1.08	N / a
K_2O	0.48	0.15	0.69	0.23	0.92	1.35	0.24	0.59	1.05	0.46	(K) 0.96	N / a
P_2O_5	0.147	0.241	0.207	0.03	0.249	0.136	0.03	0.428	0.63	0.45	N / a	N / a
La	5. 2	7.3	12.8	0.8	18.5	16	1	17	27.1	10	N / a	6.8
Ce	13	19	24	1.8	35	29	1.7	37	59	22.3	1.1	21
Nd	10	15	16	1.5	25	22	1.5	25	29.7	12.3	0.32	N / a
Sm	3.5	5.2	4.1	0.2	3.9	3.4	0.2	4.7	6.48	3.21	0.085	1.2
Eu	1.21	1.61	1.3	0.04	1.2	0.9	0.055	1.7	2	1.24	0.165	0.47
Gd	4	6.6	4.3	1	3	2.3	1	3.6	N / a	N / a	0.065	N / a
Tb	0.8	1.17	0.73	0.05	0.57	0.25	0.025	0.7	0.76	0.51	N / a	0.35
Yb	3	5.1	2.6	0.15	2.2	1.8	0.2	2.7	1.7	1.33	0.028	0.21
Lu	0.453	0.768	0.374	0.02	0.3	0.25	0.03	0.4	0.27	0.19	N / a	N / a
Ba	66	80	386	9	178	118	14	79	513	169	8.9	84
Rb	6	3	11	2	8	40	2	9	21.3	4.8	2.55	N / a
Th	0.4	0.5	1.5	0.3	2.6	3	0.2	1.6	2	1	N / a	2.2
Nb	5.05	9.5	30.4	0.1	6.8	5.3	0.3	31.9	31.6	14.3	N / a	N / a
Ta	0.287	0.34	1.305	0.1	0.25	0.2	0.1	1.3	1.7	0.65	N / a	0.1
Sr	191	134	422	4	347	600	5	382	938	330	7.1	N / a
Zr	104	157	104	4	170	141	11	220	136	95	N / a	32
Hf	2.5	4.2	2.6	1	3.9	2	1	3.4	2.9	2.2	N / a	0.92
Y	33.5	54.6	27.6	0.1	25.9	21.6	1.6	34.4	21	15	N / a	N / a

Note: Kaula plagioclase basanite (KB), tholeiitic basalt (KT), Hawaiian oceanic islands (Clague and Frey, 1982; Garcia et al., 1986), hydrothermal solution seepage from the ocean floor (East Pacific Rise, 21° N latitude), hydrothermal ore breccia from the mid-oceanic ridge (Atlantic Ocean, 26°06 N latitude) are presented for comparison (Lisitsyn et al., 1990, 1993). N/a–not-analyzed. Analyses were performed in the Analytical Center UIGGM, SB RAS: petrogenic elements – by roentgeno-fluorescence (by N.M. Glukhova) and atomic-absorption (by L.D. Ivanova) methods, rare and rare-earth elements – by roentgeno-fluorescence (by Yu.P. Kolmogorov), and neutron-activation (by V.A. Bobrov and V.S. Parkhomenko) methods.

(1983) the compositional points concentrate in three fields: MORB (C-9912), island arc tholeiite (C-997, C-9914A) and alcali oceanic islands basalts (C-007-3) (Fig. 3A). Geochemical investigations of the minor elements and REE indicate that they belong to oceanic island basalts and middle oceanic ridge basalts. Figure 3B shows the Hf/3-Th-Ta diagram (Wood, 1980) where sample C-9914A falls in the OIB field, samples C-997 and C-9912 in the N-MORB field and sample C-007-3 in the E-MORB field. Concentrations of the REE in the Zasur'ya Group basaltoids (Fig. 4) and in their tuffs (Fig. 5) in 10 or 100 times exceed their contents in chondrites. The REE contents for the Zasur'ya jasperoids is 10–1000 times lower than their concentrations in the modern hydrotherms (Fig. 6). At the same time, common negative inclination of the curves is observed. The plots suggest that the rocks analyzed are oceanic island alkali basalts and E-MORB basalts, rather than convergent margin calc-alkaline basalts (Fig. 3).

These studies in the Gorny Altai segment of the Paleo-Asian Ocean allow specification of several lithological markers and bio-indicators, along with geochemical indicators of oceanic sedimentary environments in the Zasur'ya strata. The combination of these markers and bio-indicators identifies the deep-water character of sedimentation in the Zasur'ya paleobasin (Khlebnikova et al., 2001; Sennikov et al., 2001, 2002, 2003).

Lithologic Characteristics

The oceanic stage of Zasur'ya sedimentation is regarded as largely independent of the volcanic-sedimentary group, and is divided into three large cycles corresponding to three lithogical associations, which also correspond to individual formations. The three associations are (a) basalt, and siliceous and terrigenous sediments, (b) terrigenous sediments, and (c) siliceous and terrigenous sediments (Sennikov et al., 2001, 2002, 2003).

The Listvenny Formation is the basal unit in the Zasur'ya Group, and comprises the basalt-siliceous-terrigenous sediment association. It consists of basalts, varicolored cherts (often lilac and dark-red), argillites, siltstones, and more rarely, sandstones. The siliceous beds are generally 0.2–10 m in thickness, and are typically finely-banded, flaggy and varicolored. On the basis of their dominant lithology, four types of sections can be identified in the Listvenny Formation: (a) mainly siliceous, (b) basal-siliceous, (c) siliceous-terrigenous, and (d) mainly terrigenous (Table 2).

The Listvenny Formation is succeeded by the Talitsa Formation, which consists of grey, green and rarely varicolored argillites, siltstones and sandstones. Greenish-colored rocks also occur among the siliceous-terrigenous beds of the Marcheta Formation, the upper formation of the Zasur'ya Group. The Talitsa Formation consists essentially only of terrigenous strata, and thus belongs to the terrigenous sediment association.

The overlying Marcheta Formation consists of varicolored cherts (often lilac and dark red), argillites, siltstones, and sandstones, and represents the siliceous-terrigenous association. The siliceous beds sometimes reach 5–25 m in thickness. The cherts are massive, monolith and monotonous. Three main types of section occur in the Marcheta Formation: (a) mainly siliceous, (b) siliceous-terrigenous, and (c) mainly terrigenous (Table 2).

Individual sections may also be characterised by specific combinations of the seven parameters, namely: (1) the general color of the rocks; (2) chert color; (3) thickness of siliceous intervals; (4) thickness of terrigenous intervals; (5) flaggy (tabular) structure of the siliceous members; (6) micro-bedding of the siliceous rocks and (7) presence of traces of subaqueous slumping (Table 2). Each of these parameters can occur in terrigenous and volcanic-siliceous-terrigenous depoisitional environments on shelfs and near volcanic arcs. However, persistent combination of all the parameters listed can be found nowhere except in deep-water oceanic environments.

Deposition of the Zasur'ya Group occurred during the Aksayian, Batyrbayian, Tremadocian and Arenigian stages, thus spanning a period of 25–30 million years. The estimated average rate of sedimentation was 15–25 to 40–50 mm per thousand years, calculated on the total thicknesses and the extent of individual formations in specific sections. For comparison, rates of accumulation of oceanic cherts about the Cambrian-Ordovician boundary in Central Kazakhstan are estimated to be 2–3 mm per thousand years (Tolmacheva et al., 2001).

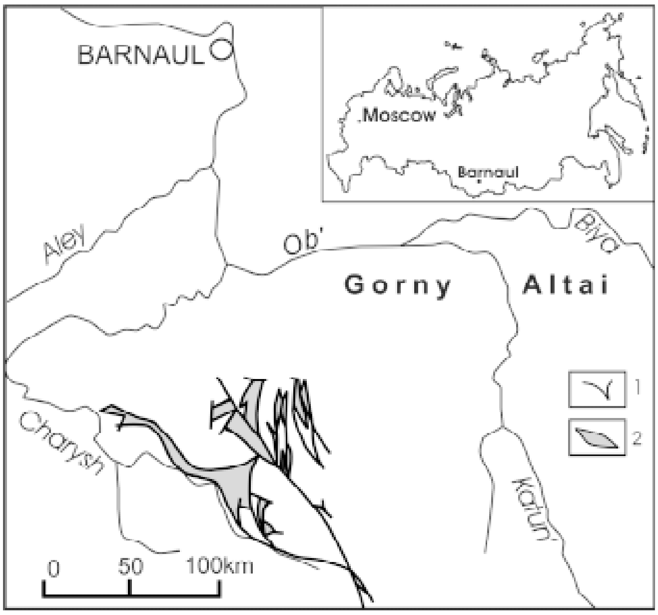

Fig. 1. Distribution of Zasur'ya Group oceanic rocks in the Gorny Altai, and location in Russia (inset). Legend: 1–tectonic contacts of the Zasur'ya Group sediments with Lower Paleozoic carbonate-terrigenous shelf strata; 2–distribution of Zasur'ya Group sediments.

Sedimentation rates of modern oceanic deep-water red marls are 3–5 mm per thousand years, and those of biogenic sediments (radiolarites and siliceous spiculites) are 10–30 mm per thousand years (Galerkin et al., 1982).

The Zasur'ya Group strata accumulated during three oceanic sedimentary cycles, each of which had an average duration of 6 to 8 million years. Each cycle coincides with one of the three formations of the Zasur'ya Group. Each is characterized by the presence or absence of volcanism (lava flows, hydrotherms) and its intensity during terrigenous sedimentation. It is especially well expressed in terrigenous members underlain and overlain by single chert members. In most cases, both have the same structure and rock color. The same characteristics were noticed for terrigenous intervals in contact with basalts.

Each of the three cycles can in turn, be subdivided into sedimentary facies lasting 3–4 million years. These reflect changes in sedimentation rates during each cycle, and a tendency for certain rock types to dominate. These subdivisions also equate with members. In contrast with the lower member exposed in the Listvenny section, basalt beds, one to tens of meters in thickness, occur with different colored cherts in the Ozernaya and Molchanikha sections of the upper member of the Listvenny Formation.

Sandstone members are relatively common in the Talitsa Formation, where they alternate with siltstones and argillites. Thicknesses of the beds in the Lower Talitsa member vary from 15 to 70 m. The sandstone interbeds almost disappear in the Upper Talitsa member, and thickness of the argillite-siltstone intervals decreases to 10–40 m.

Siliceous interbeds are characteristic of the lower member of the Marcheta Formation (Charysh, Marcheta-2 and Marcheta-3 sections), but are virtually absent from the upper member (Charysh section). Terrigenous

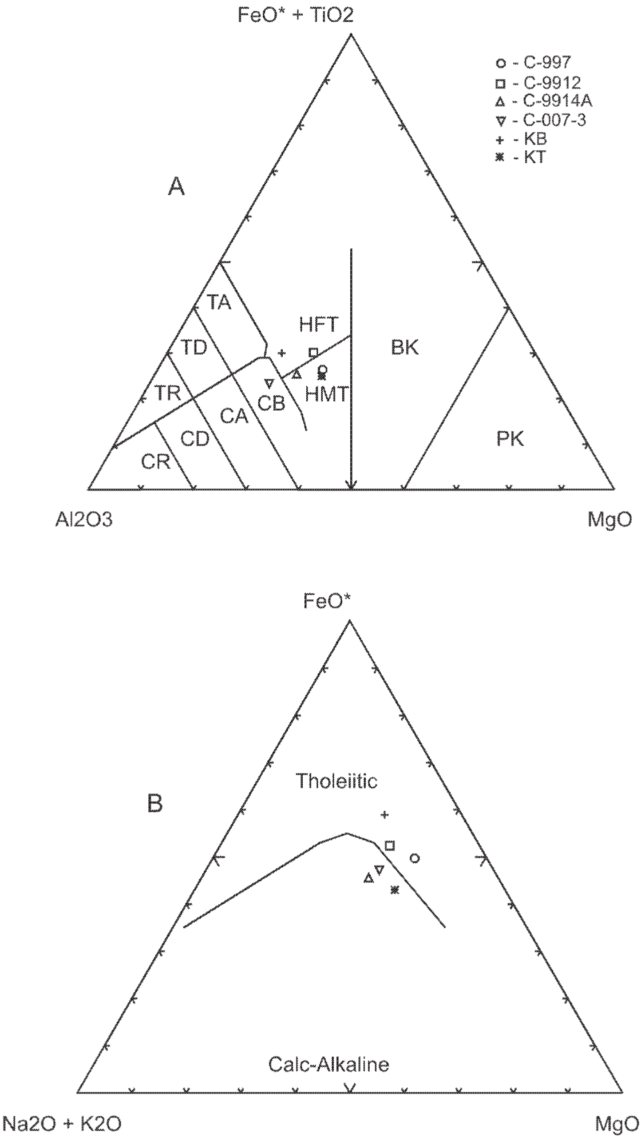

Fig. 2. Major element compositions of Zasur'ya Group oceanic basalts. (A) Al_2O_3–FeO*+TiO_2–MgO and (B) Na_2O+K_2O–FeO*–MgO diagrams for Zasur'ya oceanic rocks compared to Kaula plagioclase basanite (KB) and Kaula tholeiitic basalt (KT) from the Hawaiian oceanic island system (Clague and Frey, 1982; Garcia et al., 1986). Data are listed in table 1. Abbreviations used: Tholeiitic series: TR–rhyolite, TD–dacite, TA–tholeiitic andesite, HFT–high-ferruginous tholeiite. Calc-alkali series: CR–rhyolite, CD–dacite, CA–calc-alkaline andesite, CB–basalt, HMT–high-magnesium tholeiite, BK–komatiitic basalt, PK–komatiite.

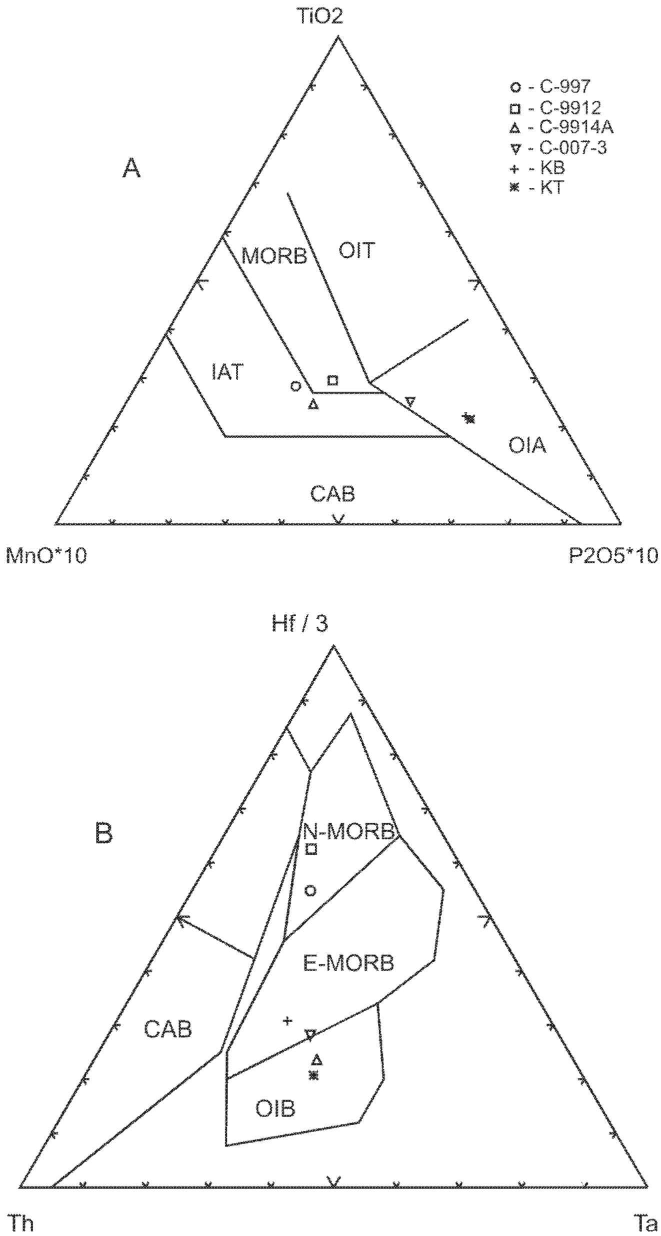

Fig. 3. Chemical composition of Zasur'ya Group oceanic basalts. (A) MnO–TiO_2–P_2O_5 (Mullen, 1983) and (B) Th-Hf/3-Ta discrimination diagrams (Wood, 1980) for Zasur'ya oceanic rocks compared to Kaula plagioclase basanite (KB) and Kaula tholeiitic basalt (KT), Hawaiian oceanic island system (Clague and Frey, 1982; Garcia et al., 1986). Abbreviations: IAT – island arc tholeiite, MORB–middle oceanic ridge basalts (E-MORB enriched, N-MORB–normal), OIT–oceanic islands tholeiite, OIA–alkali oceanic islands basalts, CAB–calc-alkaline basalts, OIB–oceanic island basalts.

intervals increase in thickness upward, from 5–10 m in the lower member to 25–50 m in the upper member.

Shorter intervals can also be identified in every member of each formation in the Zasur'ya Group. On average, 20–30 intervals occur within individual sections, and each interval represents periods of 100 to 200 thousand years. The flaggy (tabular) structure of these intervals may reflect the rhythmic character of sedimentation processes lasting only 0.5–2 thousand years. We consider that microbedding and micro-flaggy (tabular) structure, the most characteristic feature of the siliceous-terrigenous sections of the Zasur'ya Group (Table 2), formed over a period of 10–50 thousand years, although some probably coincided with shorter episodes of sedimentation.

The Listvenny, Talitsa, and Marcheta Formations were all deposited on the ocean floor under conditions of varying relief and at varying accumulation rates. The Listvenny Formation was deposited on a relatively even surface, judging by the scarcity of subaqeous slumping within it. Only the Molchanikha section contains traces of possible subaqueous slumping, as represented by syngenetic breccia. In contrast, the siliceous and terrigenous rocks of the Marcheta Formation were deposited on an ocean floor with irregular relief. Seamount, OIB and MORB zones all contain positive bottom structures and thus are potential depositional sites for Marcheta sediments. Traces of subaqueous slumping can be observed in the Charysh, Marcheta-1, Marcheta-2, Marcheta-3, and Kamyshenka sections of the Marcheta Formation. The structures observed inlcude syngenetic puckering in siliceous rocks, isolated semi-spherical jointing in siliceous rocks ("twisting"), and syngenetic breccias in fine-grained terrigenous rocks. Deformation of beds caused by slickensides and displacements are also observed. The upper surfaces of slumped beds are usually gently undulose.

Lithological Markers of the Deep-water Environments

Lithological markers and specific features of sedimentation paralleling the above indicators of oceanic conditions can also be identified. These are:

(1) Co-occurrence of siliceous and terrigenous intervals with basalts.

(2) Prevalence of terrigenous intervals in the strata of the siliceous-terrigenous association. Terrigenous intervals constitute 10 to 20% of the total thickness of some sections.

Table 2. Lithologic characteristics of Zasur'ya Group sections.

Lithological type	Section	Formation	Prevailing rock color	Thickness of siliceous members (m)	Thickness of terrigenous members (m)	Flaggyness of siliceous members (cm)	Micro-bedding (micro-flaggyness) of siliceous rocks (mm)	Traces of subaqueous slumping
Mainly siliceous	Charysh	Marcheta	Lilac	5 to 25	3 to 50	3–10		
	Kamyshenka	Marcheta	Red	3–5	About 10			Present
	Listvenny	Listvenny	Lilac-red	3–10	10 to 100	5–7		
	Kyrlyk-1	?	Lilac	3–5		2–5		
	Turnaev-1	?	Chocolate	Up to 20	Up to 60	5–10		
Basalt-siliceous-terrigenous	Ozernaya	Listvenny	Grey and red	1–3	20–25			
	Molchanikha	Listvenny	Grey-green	3–5	0.5 to 16	3–5		Present
	Turnaev-2	? Listvenny	Grey-green and lilac	3–5	5 to 20	3–5		
	Tabunka	? Listvenny	Grey-green	8	2 to100	1–5	0.5–2	
	Komikha-4	? Listvenny	Dark-grey	3	1 to 60	1–3	1–2	
Siliceous-terrigenous	Komikha-1	?	Green-grey	1–2	30 to 70	1–2	0.01–0.02	Present
	Kyrlyk-2	?	From grey to lilac	0.5 to 6	2 to 30	0.5–2	0.05–0.1 and 0.1–0.2	
	Marcheta-1	Marcheta	Light-greenish-grey	Up to 2	2 to 20	1–3		Present
	Marcheta-2	Marcheta	Grey, green to red	2 to 8	1 to 120			Present
	Marcheta -3	Marcheta	Lilac-red	2–3	3 to 150		0.5–3	Present
	Berezovka	Listvenny		?	?			
	Sosnovka-1	?	Grey	1	50-100			
Mainly terrigenous	Talitsa	Talitsa and Marcheta	Grey to lilac	2 to 10	10 to 50	1–10	1–2	
	Telezhikha	?	Grey		About 100			
	Zagrikha	Listvenny		?	?			
	Komikha-2	? Talitsa	Greenish-grey	5	About 100	1–2	0.1–0.2	
	Sosnovka-2	?	Grey-green and lilac		50–100			

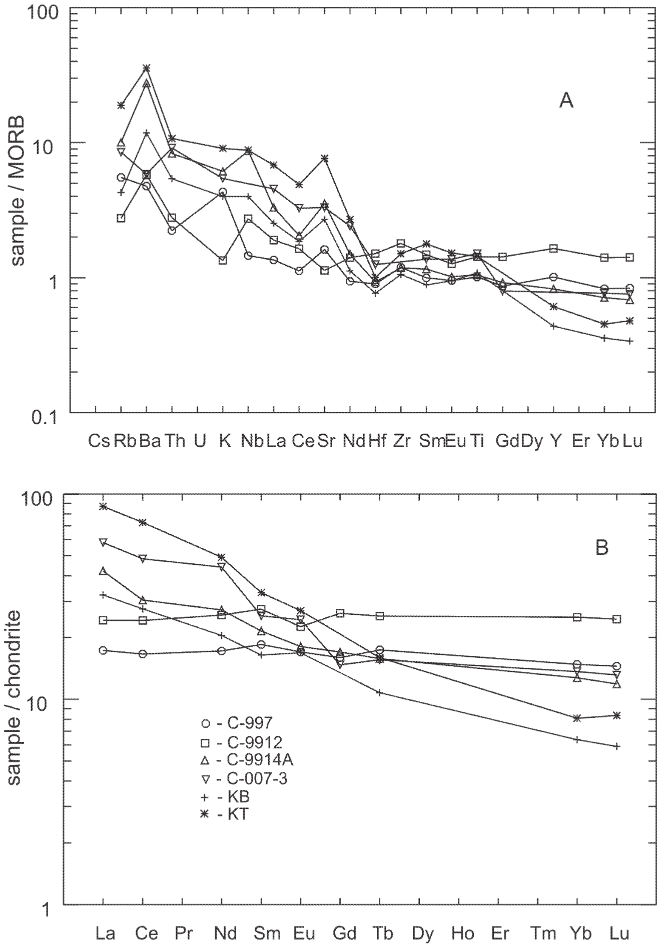

Fig. 4. Distributions of rare-earth and other elements in Zasur'ya Group basalts. (A)–MORB-normalized multi-element plot: (Taylor and McLennan, 1985); (B)–Chondrite-normalized REE abundances (Boynton, 1984).

(3) Presence of thick terrigenous intervals, ranging from 2–5 to 25–30 m in thickness. Chemical saturation of the bottom waters by silica did not occur during accumulation of the Talitsa Formation, and bio-productivity of the silica-precipitating microorganisms was extremely low. Conditions for precipitation of silica during accumulation of the Listvenny Formation were moderately favorable, and rather more favorable during deposition of the Marcheta Formation.

(4) Presence of non-flaggy, monotonous, and unvariegated cherts (beds up to 2–5 m thickness).

(5) Regular micro-bedding within the siliceous layers, at scales ranging from 0.01–0.02 to 1–2 mm (Table 2, Fig. 7).

(6) Prevalence of red-brown and lilac hues among siliceous and terrigenous sediments.

(7) Occurrence of radiolarites and spiculites. Siliceous sponge associations developed on the floor of the paleobasin during accumulation of the Listvenny and Marcheta Formations, while radiolarian associations populated the pelagic zone. This resulted not only in formation of siliceous interbeds, but also in deposition of spiculites and radiolarites (Klebnikova et al., 2001).

(8) Thicknesses of the intervals in the terrigenous parts of the sections range from 10 cm to several meters, and sometimes reach 100 m. As a rule, grain size decreases upwards in specific intervals. The lower boundaries of sandstone intervals are sharp, whereas the upper boundaries frequently grade into siltstone intervals. Graded bedding was not observed. Sandstone-siltstone members are intercalated with siliceous members. These characteristics suggest these deposits represent distal turbidites.

(9) Gentle cross-bedding is observed in some sections, whereas gradational stratification and micro-bedding is absent. Varicolored and red radiolarian-bearing siliceous rocks apparently formed under deep-water conditions,

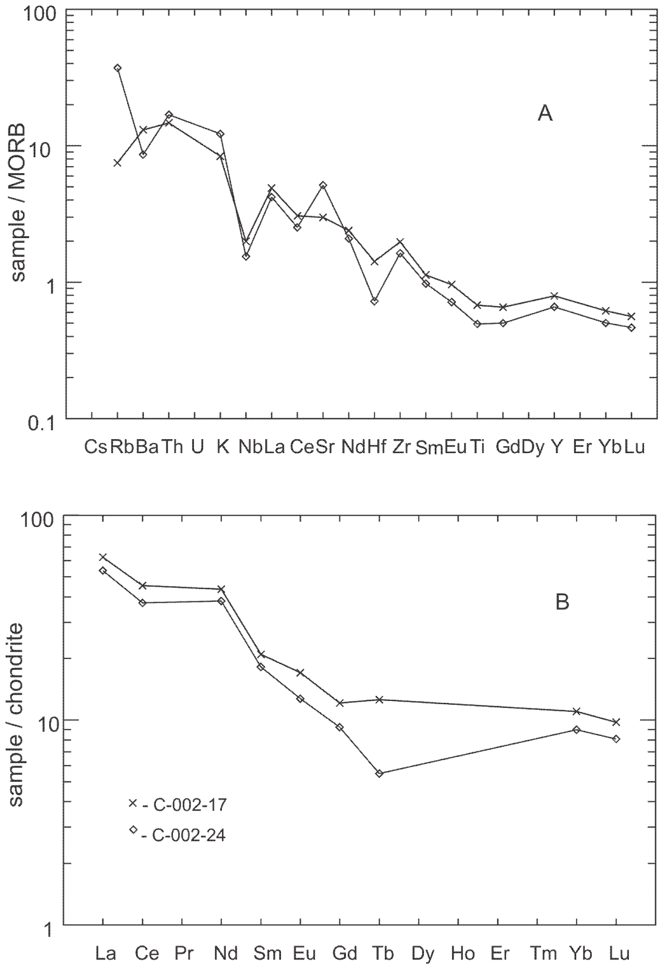

Fig. 5. Distributions of rare-earth and other elements in Zasur'ya Group tuffs. (A)–MORB-normalized multi-element plot: (Taylor and McLennan, 1985), (B)–Chondrite-normalized REE abundances (Boynton, 1984).

with well-aerated bottom currents. These deposits may therefore be contourites.

(10) Presence of deposits connected with hydrothermal activity at vents. Thick intervals of monotonous, unlaminated cherts in the Marcheta Formation likely formed in the bottom of the paleobasin near sites of outflow of hydrothermal solutions. Moreover, in one Marcheta Formation section (Marcheta-2), a large lens-shaped body (Fig. 8) consisting of ferruginous quartzites (jasperoids) forms a hillock 6 m high and 40–50 cm in diameter. Smaller bodies of similar composition also occur within a radius of 100–200 m. A lens in the Komikha-2 section is similar in shape and composition. These characteristics suggest these bodies represent oceanic hydrothermal sedimentation of the linear type. In modern oceans, seafloor hydrothermal fields reach a few hundred meters in diameter. Hydrothermal fields occur in modern

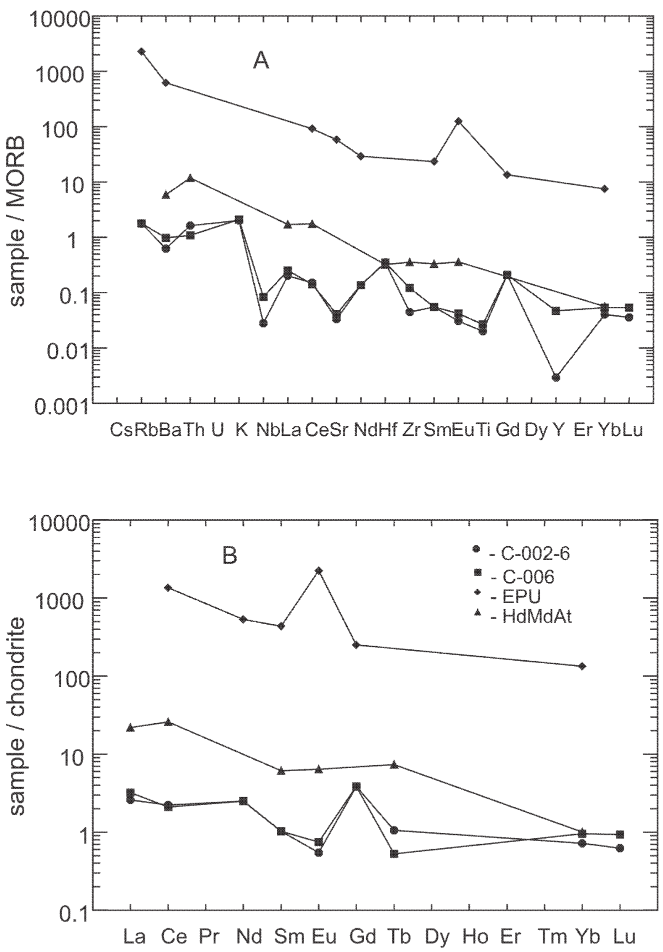

Fig. 6. Distributions of rare-earth and other elements in Zasur'ya Group hydrothermal deposits compared to East Pacific Uplift (EPU) hydrothermal solution and Atlantic MORB hydrothermal breccia (HdMdAt). (A)–MORB-normalized multi-element plot (Taylor and McLennan, 1985), (B)–Chondrite-normalized REE abundances (Boynton, 1984).

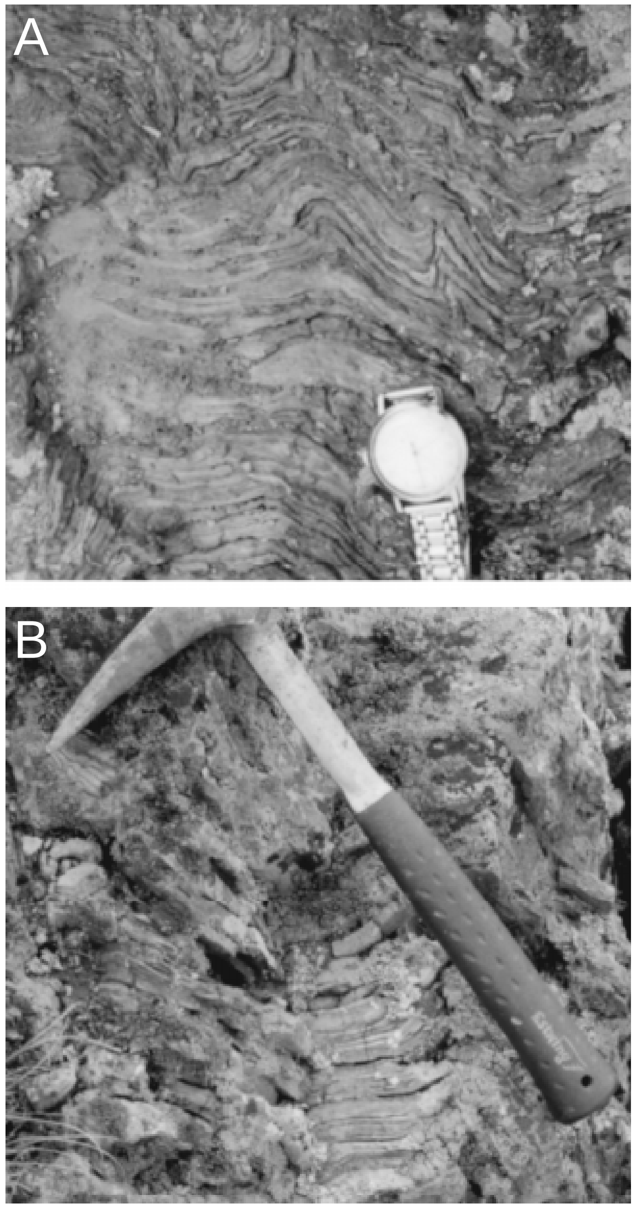

Fig. 7. Flaggy (tabular) structures (ranging from 1–2 cm in thickness) and microlamination (ranging from 0.01–0.02 to 1–2 mm) in the oceanic cherts of the Zasur'ya Group (Komikha-1 section).

MORB zones at spacings of tens to hundreds of kilometers, and hydrothermal activity is lacking in the intervening areas (Lisitsyn et al., 1990, 1993). Comparison of rare-earth element distributions in the Zasur'ya Group hydrothermal deposits with modern hydrothermal solutions from the East-Pacific Rise (21° northern latitude) and modern ore breccia formed on the Mid-Atlantic Ridge at 26°06 north latitude (Lisitsyn et al., 1993) shows similar trends for most elements (Fig. 6). Broad differences may be explained by metasomatism occurring after precipitation of minerals deposited during formation of the hydrothermal structures.

(11) Lack of evidence for the effects of waves.

(12) Absence of carbonates and calcareous cement in Zasur'ya Group terrigenous rocks, indicating accumulation occurred below the calcium carbonate compensation depth.

Bio-indicators of Deep-water Environments

The following bio-indicators of deep-water environments are indicated by our study of the Zasur'ya Group (Table 3):

(1) The faunal associations observed consist only of nektonic conodonts, planktic radiolarians, and siliceous sponges. Graptolites, which are typically widely distributed in shelf environments, have not yet been found in the Zasur'ya Group. Moreover, benthos with calcareous and phosphatic skeletons are also absent, and bioturbation traces do not occur. Traces of detritivore activity and burrows of benthic groups were not found in the broad spectrum of terrigenous sediments examined, from sandstones through siltstones and argillites.

(2) Faunal remains were obtained mainly from cherts, and much less from siliceous mudstones and siltstones. For siliceous sponges, this is due to their living in areas favorable for growth of silica-precipitating microorganisms. Occurrence of radiolarians with siliceous skeletons may suggest the presence of areas of intense, ascending, nutrient-rich waters. Conodonts with phosphate skeletons are present only in the siliceous rocks. At present, the reason for this is unknown, and additional specialized study is required. The simplest explanation may be that cherts are the best lithologies for preservation of discrete separate elements, as well as for entire apparatus (Tolmacheva and Purnell, 2002). Faunal remains have not been found in white, grey or green cherts. Most faunas occur in red cherts. Geochemical analyses of varicolored cherts are required to establish the reason for this absence.

(3) Conodont associations are relatively rich in taxonomic diversity (up to 10–12 species), but specimens are less abundant (no more that 20–30 specimens per locality). They are represented by simple and multi-element apparatuses.

(4) Siliceous sponge associations are numerous and frequently rock-forming, but are monotonous in composition (about 2–4 species). The low taxonomic diversity of the siliceous sponge spicules requires further investigation.

Table 3. Relation of faunal associations to Zasur'ya Group lithologies.

Lithological types	Section	Formation	Color of cherts and siliceous mudstones yielded fauna	Quantity of localities with fauna	Population density			Taxonomic diversity		
					Conodonts	Radiolarians	Siliceous sponges	Conodonts	Radiolarians	Siliceous sponges
Mainly siliceous	Charysh	Marcheta	Red, lilac	Many	Medium	High	Few	Medium	?	Small
	Kamyshenka	Marcheta	Red	Few	Low	High	Medium	Small	Small	Small
	Listvenny	Listvenny	Red	Medium	Medium	D/a	Few	High	D/a	Small
	Turnaev-1	?	Chocolate, grey	Few	D/a	Small	Not present	D/a	D/a	Not present
Basalt-siliceous-terrigenous	Ozernaya	Listvenny	Red, grey, green	Few	Medium	Low	Few	High	Small	Small
	Molchanikha	Listvenny	Red	Few	Low	Medium	Few	Scarce	Small	Small
	Turnaev-2	? Listvenny	Lilac	Few	D/a	D/a	Not present	D/a	D/a	Not present
Siliceous - terrigenous	Marcheta-2	Marcheta	Red	Many	Medium	Medium	Few	Small	Small	Small
	Marcheta-3	Marcheta	Red	Medium	Small	Small	Few	Medium	Small	Small
	Berezovka	Listvenny	Lilac	Few	Low	D/a	Few	Small	D/a	Small
	Sosnovka-1	?	Green, brown	Very few	D/a	Low	Few	D/a	Small	Small
Mainly terrigenous	Talitsa	Talitsa and Marcheta	Violet-lilac, Red, grey	Few	Small	Low	Not present	Medium	D/a	Not present
	Zagrikha	Listvenny	Lilac	Few	Low	D/a	Few	Small	D/a	Small

Quantity of localities with fauna	Population density	Taxonomic diversity
1 locality – Very few (or rare) 2-4 – localities – Few 5-7 – localities – Medium more than 8 localities – Many	1-5 specimens – Low 6-10 specimens – Small 11-20 specimens – Medium more than 20 specimens – High (spongolite, radiolarite)	1 species or genus – Scarce 2-4 taxa – Small 5-7 taxa – Medium more than 8 taxa – High
	D/a – data absent	D/a – data absent

Fig. 8. Oceanic hydrothermal structure in the Zasur'ya Group (stratotype section of the Marcheta Formation).

(5) Radiolarian associations are also numerous, but are rarely rock-forming. They possess low taxonomic diversity (up to 6 species) but relatively high abundance (more than 30 specimens at some localities). Radiolarites occur in the middle formation of the Zasur'ya Group.

Conclusions

The Lower Paleozoic oceanic basalt-siliceous sediment-terrigenous sediment associations of the Gorny Altai segment of the Paleo-Asian Ocean are indicative of deep-water sedimentation environments, rather than a position near a convergent or continental margin. Faunal assemblages also show oceanic associations of marine organisms, rather than shelf environments. Hydrothermal activity was also locally important. Silica deposition was biogenic in nature, with silica-precipitating microorganisms (radiolarians and siliceous sponges) playing the main role in silica deposition.

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