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Lithological and geochemical features of the Lower Triassic reservoirs in the north of Sorokin Swell (Timan-Pechora oil and gas-bearing province)

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The paper describes lithological and geochemical features of the Lower Triassic sandstones from the far north of Timan-Pechora oil and gas-bearing province. These sandstones chemically coincide to typical graywackes.

We discuss how sedimentation environments and diagenesis control the local heterogeneity of cementation, variability of void space and the potential oil content.

Tectonic conditions are one of the provenance factors, the figurative points of the composition of sandstones on the diagrams fall into the field of the passive continental margin. The position of sandstone points on the diagrams and low values of the hydrolyzate module indicate the formation of deposits in an arid climate, which does not contradict to geological data.

Keywords: *Triassic deposits, sedimentation, facies, environments, sandstones, graywackes, oil and gas reservoirs, geochemical module.*

Литологические и геохимические особенности нижнетриасовых резервуаров на севере вала Сорокина (Тимано-Печорская нефтегазоносная провинция)

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Исследования в области условий образования природных резервуаров доказали, что они в значительной степени предопределены древними обстановками осадконакопления, тесно связанными с тектоническим планом территорий. Актуальность темы определяется необходимостью детального изучения морфологии и фильтрационно-емкостных характеристик природных резервуаров. Цель исследования состоит в анализе литолого-геохимических особенностей песчаников, вмещающих залежи углеводородов, а также положения областей их составов на дискриминантных диаграммах. Объектом исследований послужили песчаники нижнего триаса северных площадей вала Сорокина. В основу работы были положены результаты силикатного анализа граувакк. Анализ химического состава песчаников показал, что они формировались за счет смешения обломков из разнородных источников сноса. Области состава песчаников на дискриминантных диаграммах изменчивые, что обусловлено вовлечением в размыв магматических, метаморфических и осадочных пород, формировавшихся в различных геодинамических обстановках.

Ключевые слова: *триасовые отложения, седиментация, фации, обстановки осадконакопления, песчаники, граувакки, резервуары нефти и газа, геохимические модули.*

Introduction

The topic is relevant because the commercial oil and gas potential of the Triassic deposits is proved by such fields as Varandeyskoe, Toraveyskoe, Labaganskoe within the Sorokin swell (Fig. 1), Kumzhinskoe, Korovinskoe — in the Denisov depression, and the oil and gas reserves and resources, confined to the Triassic deposits, are quite large [7,8]. Nevertheless, there are many unresolved problems concerning the conditions of distribution and structural features of natural reservoirs confined to this oil and gas complex. The paper aims to study lithological and geochemical features of the structure of natural reservoirs and to identify criteria for their diagnosis.

Oil and gas reservoirs are geological bodies consisting of reservoir beds, lenses, and layers of weakly and impermeable rocks of intra-reservoir seals, forming a common (single) hydrodynamic system. It is constrained below and above by inter-reservoir seals. Accumulation of hydrocarbons in the reservoir and their safety are determined by the quality of each element. The structural features of sedimentary layers control the distribution of collectors and seals in them, their relationship, and ultimately the morphology and properties of reservoirs.

Environments and their effects on reservoir quality have particular interest for the study of clastic reservoirs.

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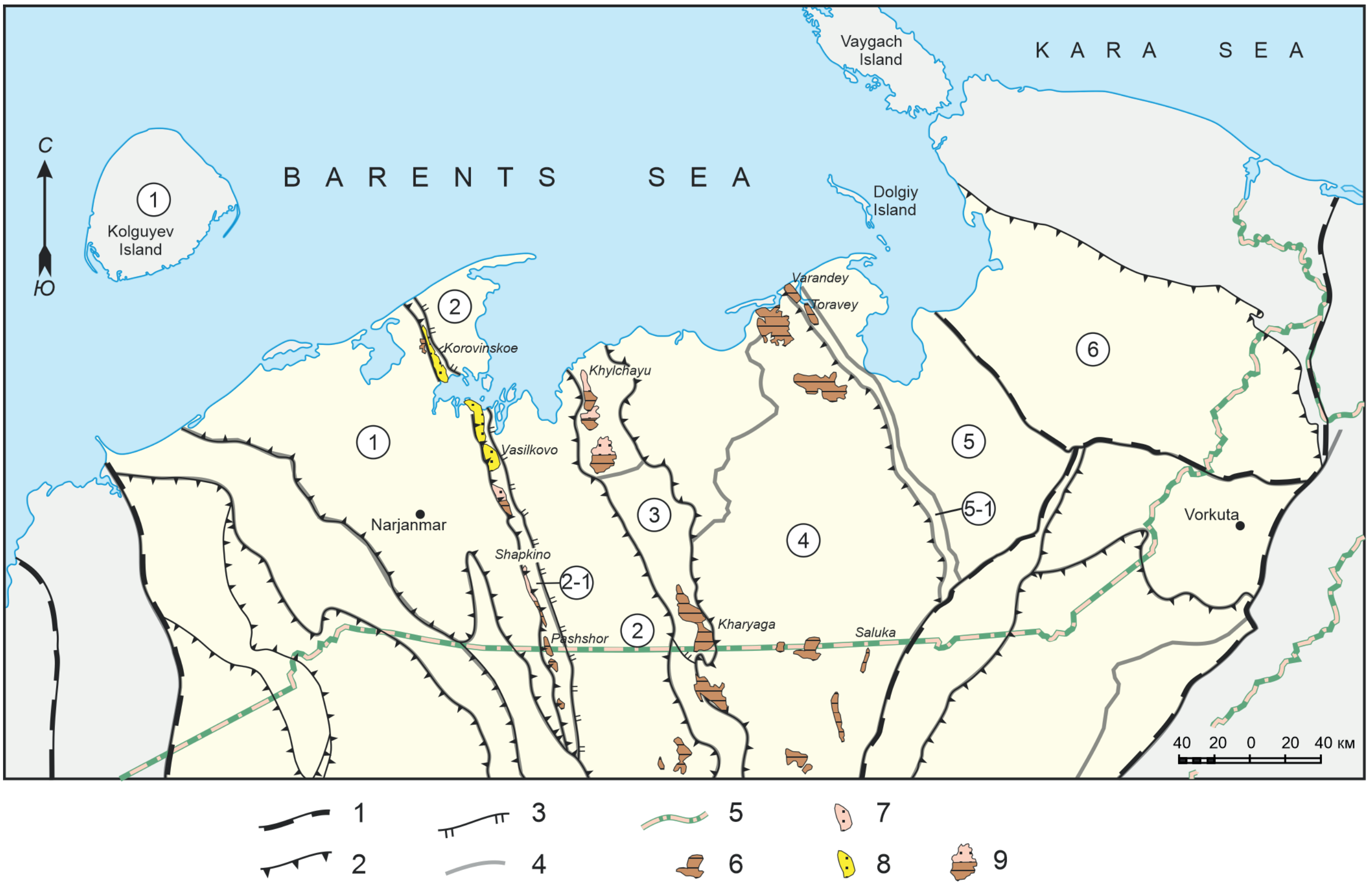

Fig. 1. Structural map of Timan-Pechora oil and gas-bearing province. Boundaries of structures: 1 — major, supra-order; 2 — large, the first order, 3 — average, the second order, 4 — borders of oil and gas bearing areas; 5 — administrative border; 6–9 — oil and gas fields: 6 — oil, 7 — gas-condensate, 8 — gas, 9 — condensate and oil. Elements of oil zoning: 1 — Malozemelsk-Kolguev monocline (oil and gas-bearing area); 2 — Denisov depression (oil and gas-bearing area); 2-1 — Shapkina-Yuryakha swell (oil and gas-bearing region); 3 — Kolva swell (oil and gas-bearing area); 4 — Khoreyver depression (oil and gas-bearing area); 5 — Varandey-Adzva structural zone (oil and gas-bearing area), 5-1 — Sorokin swell (oil and gas-bearing region); 6 — Korotaikha depression

Рис. 1. Тектоническая схема Тимано-Печорской нефтегазоносной провинции. Границы структур: 1 — крупнейших, надпорядковых; 2 — крупных, первого порядка, 3 — средних, второго порядка; 4 — границы нефтегазоносных районов; 5 — административная граница; 6–9 — нефтяные и газовые месторождения: 6 — нефтяные, 7 — газоконденсатные, 8 — газовые, 9 — смешанного состава. Элементы нефтегазогеологического районирования: 1 — Малоземельско-Колгуевская моноклиналь, 2 — Денисовская впадина, 2-1 — Шапкина-Юрьяхинский вал, 3 — Колвинский мегавал, 4 — Хорейверская впадина, 5 — Варандей-Адзьвинская структурная зона, 5-1 — вал Сорокина, 6 — Коротаихинская впадина

A lot of researchers studied problems of formation of natural reservoirs and recognizing the depositional environments [1,11,12,19]. The modeling was based on the idea that the structural features, morphology and reservoir properties of natural reservoirs depended on both sedimentogenesis and the intensity of diagenetic transformations [9,11,17, 22].

The lithological and geochemical characteristics of sedimentary rocks gives useful information on the origin, tectonic settings, palaeoclimate and weathering patterns, transport system and diagenesis [6]. The sedimentological reconstructions were based on the idea that the morphology and filtration characteristics of natural reservoirs were largely predetermined by ancient sedimentation situations, which were closely associated with the tectonic history of the territories. Hydrocarbon accumulation occurred in Triassic rocks largely in the northern part of the basin. Varandeyskoe, Toraveyskoe, Labaganskoe fields of the Sorokin swell, Kumzhinskoe, Korovinskoe in Denisov depression are main pools. Triassic complex includes large resources of hydrocarbons [12, 19].

Geological setting

Triassic oil and gas bearing complex has a regional distribution. The central parts of the Korotaikhinsky and Bolshesyninsky basins have the maximal thickness of the Triassic formation (2.8–3.6 km). The Izhma-Pechora basin is less thick (100–500 m). The Triassic succession of entirely continental strata is subdivided into the lower, middle and upper parts. The Triassic succession comprises a relatively monotonous complex with different volume of grey-colored sandstones, siltstones, shales and conglomerates. Stratification and correlation of these deposits are often rather uncertain. Therefore, many local suites are distinguished in different parts of the basin.

The Lower Triassic includes Charkabozhskaya and Kharaleyskaya suites. The thickness of the first one varies from the first meters in the southwest (in the Seduyakha swell) to 380 m in the central part of the Kolva megaswell, the Khoreyver depression, the thickness of the suite averages 150–250 m [7,19,21].

Entsova F. I. and Kalantar I. Z. first described the Charkabozhskaya suite at the outcrop near the Charkabozh village in 1966 [7]. The deposits of this suite overlay Upper Permian rocks, but sometimes older deposits. The Charkabozhskaya suite is represented by interbedding of red-colored clayey rocks with siltstones, sandstones and conglomerates, predominantly green and grayish-green in color. As a rule, at the base of the section there is a layer of conglomerates or sandstones with gravel and pebbles of quartz, flint, metamorphic and sedimentary rocks. The thickness of this layer varies from several meters to 35–45 meters. Above the basal layer, alternating layers of red-brown and chocolate-brown clays and grayish-green sandstones and siltstones follow with bluish spots. The thickness of sandstone layers is from several centimeters to 10–20 meters, siltstones and clays — up to 5–50 meters, while the thickness and number of sandstone layers decreases from south-east to north-west.

Results and discussion

The paper presents results of the study of core material after drilling in the north of the Sorokin swell of the Varandey-Adzva structural zone.

Our research is based on the study of sandstones by the classic chemistry method, carried out at the Institute of Geology of the Federal Research Center of the Komi Scientific Center of the Ural Branch of the Russian Academy of Sciences. We used the lithological and petrographic methods and well-logging were used. We carried out a detailed study using a polarizing microscope, a scanning electron microscope, X-ray diffraction. More than 700 samples were taken from the productive layers and impermeable intervals of 8 wells for detailed study of the petrographic composition of clastic rocks, the mineral composition of sandstone cement, lithogeochemical studies and reservoir properties of the sediments. Geochemical characteristics were calculated on the basis of chemical (silicate) analysis of more than 85 samples.

Detailed facial reconstructions proved the alluvial genesis of deposits, a fractional subdivision of alluvial deposits was carried out (Fig. 2). The facies of the water channel and the channel bar microfacies and the inner part of the floodplain were identified. Sediments of the water channel facies have subordinate importance and small thickness, they are confined to the lower parts of the sandy body and are composed of the largest fragments of flint, quartz, igneous rocks and clays, both brought by the river during floods and formed from the bedrock of the channel. These deposits are confined to the zone of the most intense erosion of the riverbed and are associated with the fastest part of the flow; their thickness rarely exceeds 0.2–0.5 meters. The deposits of the near-river part of the channel and the near-channel shoal fill the entire axial and adjacent parts of the channel incision, i.e. between the core zone and the outer part of the floodplain in the zone of gradual weakening of the turbulent flow velocity.

The fluvial macrofacies consist of the deposits of braided and meandering rivers. The braided channel facies are subdivided into the water channel and the channel bar microfacies. Braided channels are unstable, moving fast in various directions. [13,16]

The middle to coarse-grained sandstones and fine-grained conglomerates are widely deposited in the first type of environments — braided rivers. The structural and compositional maturity is low with medium-sorted subangular grains. Erosion surfaces are commonly observed at the bottom of channels.

Middle to small sized cross-bedding is developed in water channel and channel bar microfacies. The overflow bank is composed of sediment bodies from two banks formed by the spilling water during the period of river flood. Fine-grained sandstones to siltstones are interbedded with mudstones.

The floodplain deposits — mudstones and siltstones, interbedded with the conglomerate — are mainly oxidation-colored (red). Horizontal bedding is commonly visible and present a period of medium-low hydrodynamic force. The development of these deposits occurred under the braided river conditions.

The next group of facies is developed on the top of Charkabozhskaya suite: siltstones to fine-grained sandstones. The point bar is represented by coarse-grained sandstones with high-value curves. Erosion surfaces are visible at the bottom, beddings are well-developed. Logging curves are mainly bell-shaped.

The floodplain microfacies of river flood are composed of oxidation-colored mudstones (red), or reduced-colored mudstones (grey, greyish-green). Horizontal beddings, small cross-bedding and root marks are visible in cores. These deposits were formed in the environment of meandering river.

Large sets of grey and greenish-grey mudstone, carbon mudstone are deposited in the shore-shallow lacustrian settings, no plant fossils are found.

Matrix of sandstones. The clastic part of sandstones is characterized by a high content of feldspar (20–25 %), the content of quartz — within 5–10 % [13]. The rock fragments include basalts, tuffs and tuff pelite of Triassic appearance. Debris acid complex is widespread, which is represented by microgranite, effusive rocks, tuffs. There are fragments of shale, clay and silty rocks, chlorites and chloritized rocks.

Epidote, magnetite, leucoxene and ilmenite are most often found among accessory minerals. Fine-grained sandstones with a horizontally layered structure are enriched by them. It is also resulted from the characteristics of the sedimentation environment. According to some researchers, the enrichment of fine-grained sandstones with titanium-containing minerals is resulted from the fact that the specific gravity of titanium minerals (ilmenite, leucoxene) is slightly different from the specific gravity of the predominant part of alluvium grains, therefore, they are not concentrated in the lower section of the bedrock.

The chemical composition of sandstones. According to Pettijohn's classification, sandstones are localized in the fields of graywacke [14] (Fig. 3). They fall into the field of polymictic (SiO_2 content 62–78 wt. %) and volcanomictic (SiO_2 content 54–64 wt. %) in accordance with classification by A. G. Kossovskaya and M. I. Tuchkova.

The median content of SiO_2 in sandstones is 63 wt.%, the content of Al_2O_3 varies from 10 to 17 wt.% with a median of 14 (Table 1). The minimum and maximum values of calcium oxide differ by an order of magnitude: 0.5 and 3.6 wt.%, with an average value of 1.8 wt.%. As for Lower Triassic mudstones, the median content of SiO_2 in sandstones is 56.7 wt.% (52.6-60.8), the content of Al_2O_3 varies from 15 to 17.8 wt.% with average 16.7 (Table 2).

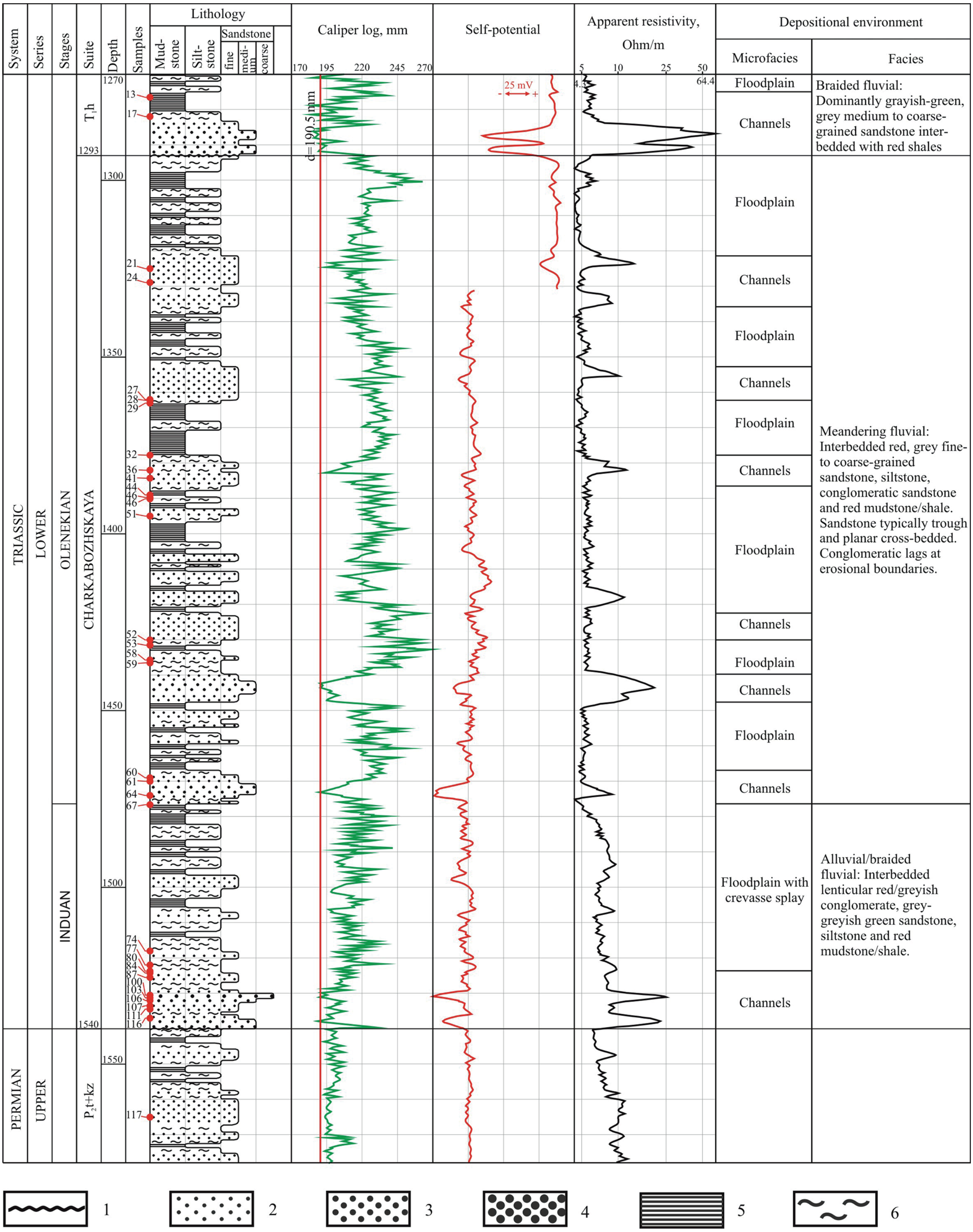

Fig. 2. Sedimentary section for the Lower Triassic deposits of Sorokin swell: 1 — erosional surface, 2 — fine-grained sandstones, 3 — medium- to coarse-grained sandstones, 4 — gritstones, 5 — mudstones, 6 — siltstones. T_1h — Lower Triassic Kharaleyskaya suite. Red dots — position of the samples

Рис. 2. Литологический разрез нижнетриасовых отложений вала Сорокина. Условные обозначения: 1 — поверхность размыва, 2 — песчаники мелкозернистые, 3 — песчаники крупно- и среднезернистые, 4 — конгломераты, 5 — глины и аргиллиты, 6 — алевролиты. T_1h — харалейская свита. Красные точки — место отбора образцов

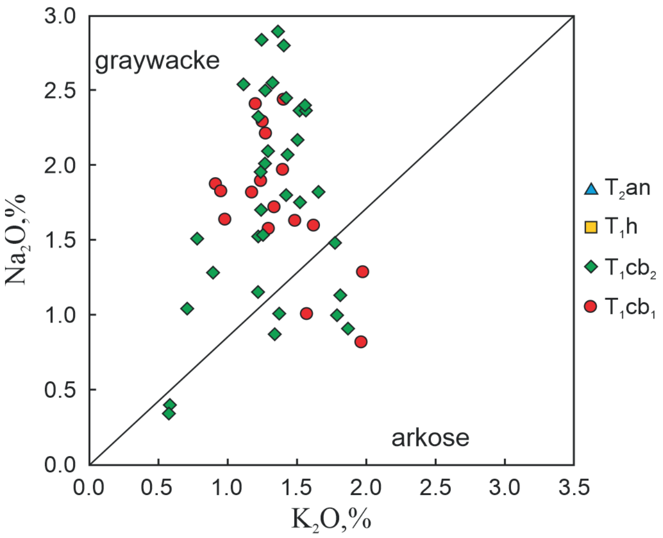

Fig. 3. Geochemical classification for terrigenous sandstones by Pettijohn: T_1cb_1 — Lower Triassic Lower Charkabozhskaya subsuite, T_1cb_2, — Upper Charkabozhskaya subsuite, T_1h Lower Triassic Kharaleyskaya suite, T_2an — Middle Triassic Anguranskaya suite

Рис. 3. Геохимическая классификация для терригенных песчаников. T_1cb_1 — нижнечаркабожская подсвита нижнего триаса, T_1cb_2, — верхнечаркабожская подсвита нижнего триаса, T_1h — харалейская свита нижнего триаса, T_2an — ангуранская свита среднего триаса

To estimate the degree of chemical weathering of parent rocks and the maturity of the material entering the sedimentation area, we calculated the hydrolysate module (coefficient), alumosilicate (AM), titanium, and sodium modules.

The limits of variation for Na_2O and K_2O are approximately comparable, with the median K_2O (1.26) being less than Na_2O (2.03). The Al_2O_3/SiO_2 ratio varies from 0.14 to 0.34 with a median of 0.23.

The hydrolysate module (ГМ=Al_2O_3+TiO_2+Fe_2O_3+ +FeO+MnO)/SiO_2) allows quantifying two most important hypergene processes — leaching and hydrolysis. The higher the module, the deeper the weathering of the rocks of the provenance area, and the smaller it is, the higher the chemical maturity of the sediments. By the size of hydrolysate module, the rocks are classified as follows: silites — less than 0.3, siallites and siferolites — 0.31–0.55, and hydrolysates — more than 0.55. Siallites and siferolites, in turn, are divided into hyposiallites (0.3–0.33), normosiallites (0.34–0.48), super-siallites (0.49–0.55). The minimum value of the hydrolysate module is 0.25, the maximum is 0.62. Based on this classification, the studied deposits belong to silites, hyposiallites, and normosiallites (Fig. 4) [23].

The maximum concentrations of the sodium module (Na_2O/Al_2O_3) were found in continental deposits in an arid climate. Plagioclases were destroyed due to chemical weathering. In our case, the values of Na_2O/Al_2O_3 vary

Table 1. Rock-forming oxide content (wt. %) and reference ratios of the Lower Triassic sandstones

Таблица 1. Содержание породообразующих оксидов (мас. %) и индикаторные соотношения для нижнетриасовых песчаников

Rock-forming oxide content	109-5	109-34	109-47	109-79	109-88	109-95	109-102	109-104	109-108	109-114
SiO_2	65.95	57.39	52.58	60.09	63.76	69.03	66.05	66.8	67.47	68.19
TiO_2	1.11	0.85	1.01	0.95	1.07	0.5	0.66	0.79	0.68	0.73
Al_2O_3	14.3	15.26	17.94	16.49	14.43	10.55	13.88	13.67	13.25	11.46
Fe_2O_3	8.9	5.27	11.06	10.41	6.2	5.35	6.3	5.35	5.31	5.44
FeO	4.8	2.57	2.6	1.84	2.42	4.37	4.73	3.47	4	3.93
MnO	0.083	0.25	0.16	0.071	0.073	0.14	0.11	0.088	0.099	0.11
MgO	1.33	4.06	4.07	2.23	2.15	1.85	2.36	2.04	2.12	2.3
CaO	0.41	3.16	1.27	0.52	2.07	3.62	1.45	1.77	1.63	2.75
Na_2O	0.34	2.07	1.13	0.82	1.58	1.82	1.9	2.08	1.95	1.54
K_2O	0.58	1.43	1.82	1.96	1.29	1.17	1.24	1.22	1.24	1.26
LOI	7.64	10.34	9.87	7.3	6.74	6.13	6.08	5.3	6.13	5.95
P_2O_5	0.04	0.17	0.14	0.11	0.21	0.14	0.16	0.17	0.16	0.16
Sum	100.6	100.25	101.05	100.95	99.57	100.30	100.19	99.28	100.04	99.89
H_2O	3.26	4.18	3.59	1.96	1.97	1.32	1.59	1.23	1.89	1.18
CO_2	0.06	1.56	0.1	0.02	0.85	2.96	1.06	0.95	1.12	1.99
HM	0.44	0.42	0.62	0.50	0.38	0.30	0.39	0.35	0.35	0.32
AM	0.22	0.27	0.34	0.27	0.23	0.15	0.21	0.20	0.20	0.17
FM	0.23	0.21	0.34	0.24	0.17	0.17	0.20	0.16	0.17	0.17
TM	0.08	0.06	0.06	0.06	0.07	0.05	0.05	0.06	0.05	0.06
Na_2O/Al_2O_3	0.02	0.14	0.06	0.05	0.11	0.17	0.14	0.15	0.15	0.13
Al_2O_3/Na_2O	42.06	7.37	15.88	20.11	9.13	5.8	7.3	6.57	6.79	7.44
K_2O/Al_2O_3	0.04	0.09	0.1	0.12	0.09	0.11	0.09	0.09	0.09	0.11
Al_2O_3/TiO_2	12.88	17.95	17.76	17.36	13.49	21.1	21.03	17.3	19.49	15.7
SPM	0.06	0.23	0.16	0.17	0.20	0.28	0.23	0.24	0.24	0.24
FM	0.89	0.50	0.73	0.71	0.56	0.89	0.77	0.62	0.68	0.78
CIA	91.49	69.62	80.96	83.32	74.50	61.48	75.15	72.95	73.33	67.37

Table 2. Rock-forming oxide content (wt. %) and reference ratios of the Lower Triassic mudstone

Таблица 2. Содержание породообразующих оксидов (мас. %) и индикаторные соотношения для нижнетриасовых аргиллитов

Rock-forming oxide content	109-10	109-17	109-26	109-29	109-36	109-53	109-59	109-71	109-74
SiO_2	58.86	59.03	55.65	54.64	52.6	54.41	55.12	60.84	59.26
TiO_2	1.25	1.09	0.91	1.09	0.89	1.09	1.08	0.93	0.9
Al_2O_3	17.79	17.24	16.84	17.26	16.01	17.13	16.41	16.24	15.12
Fe_2O_3	10.28	5.97	8.01	10.19	9.21	10.55	11.16	9.05	4.82
FeO	5.12	2.45	2.52	2.25	3.12	1.69	2.51	2.22	2.83
MnO	0.09	0.15	0.15	0.13	0.15	0.11	0.12	0.064	0.21
MgO	1.42	2.85	4.19	3.26	4.88	3.79	3.7	2.6	2.77
CaO	0.53	1.76	2.06	1.37	2.69	1.05	1.38	0.57	4.36
Na_2O	0.4	1.52	1.82	1.00	1.49	1.01	1.6	1.29	1.63
K_2O	0.58	1.22	1.65	1.79	1.77	1.57	1.62	1.97	1.48
LOI	9.17	9.4	9.97	9.99	10.64	9.87	8.91	7.22	9.78
P_2O_5	0.061	0.18	0.2	0.16	0.22	0.15	0.15	0.16	0.2
Sum	100.4	100.41	101.45	100.88	100.55	100.73	101.25	100.93	100.53
H_2O	2.71	3.53	3.86	4.02	4.34	4.13	3.39	2.14	2.01
CO_2	0.09	0.62	0.33	0.08	1.24	0.08	0.04	0.03	1.78
HM	0.59	0.46	0.51	0.57	0.56	0.56	0.57	0.47	0.40
AM	0.3	0.29	0.30	0.32	0.30	0.31	0.30	0.27	0.26
FM	0.29	0.19	0.26	0.29	0.33	0.29	0.32	0.23	0.18
TM	0.07	0.06	0.05	0.06	0.06	0.06	0.07	0.06	0.06
Na_2O/Al_2O_3	0.03	0.07	0.1	0.11	0.11	0.1	0.1	0.13	0.1
Al_2O_3/Na_2O	14.25	15.82	18.51	15.84	17.99	15.72	15.19	17.46	16.8
K_2O/Al_2O_3	0.02	0.09	0.11	0.06	0.09	0.06	0.10	0.08	0.11
Al_2O_3/TiO_2	44.48	11.34	9.25	17.26	10.74	16.96	10.26	12.59	9.28
SPM	0.06	0.16	0.21	0.16	0.20	0.15	0.20	0.20	0.21
FM	0.81	0.47	0.60	0.69	0.74	0.68	0.79	0.66	0.49
CIA	92.18	79.30	75.28	80.58	72.91	82.51	78.11	80.92	66.93

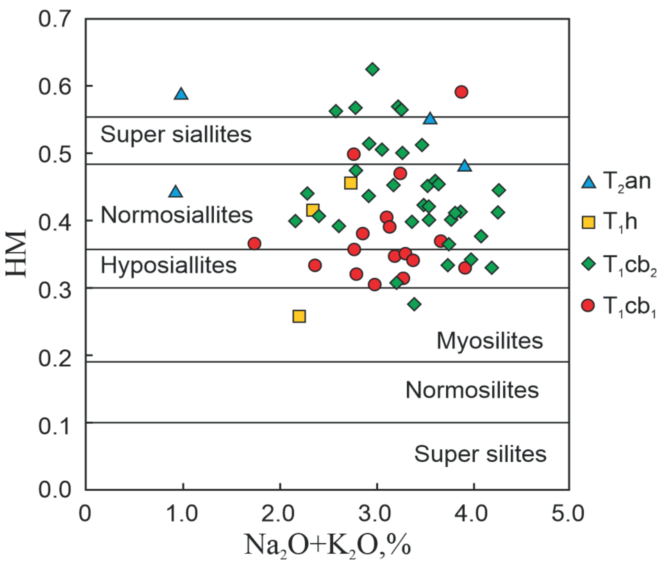

Fig. 4. Chemical composition of Triassic sandstones. T_1cb_1 — Lower Triassic Lower Charkabozhskaya subsuite; T_1cb_2 — Upper Charkabozhskaya subsuite; T_1h — Lower Triassic Kharaleyskaya suite; T_2an — Middle Triassic Anguranskaya suite

Рис. 4. Модульная диаграмма ГМ — (Na_2O+K_2O). Поля: нормосиаллит, гипосиаллит, миосиаллит, нормосиллит, суперсиллит, гиперсиллит. T_1cb_1 — нижнечаркабожская подсвита нижнего триаса; T_1cb_2 — верхнечаркабожская подсвита нижнего триаса; T_1h — харалейская свита нижнего триаса; T_2an — ангуранская свита среднего триаса

within 0.15–0.22, and sandstones characterized with Na_2O/Al_2O_3 more than 0.2 belong to graywackes.

The potassium module ratio K_2O/Al_2O_3 shows the distribution of potassium and aluminum among rock-forming minerals. Its values (0.08-0.17) indicate the dominance of clay minerals over potassium feldspars and mica.

The CIA value for sandstones varies from 61.5 to 91.5 with an average value of 75, which confirms the fact that the precipitation occurred in an arid climate.

According to Ya. E. Yudovich and M. P. Ketris, femic module values ($FeO+Fe_2O_3$+ MgO)/SiO_2) over 0.1 are typical to volcanoclastic graywackes (Fig. 5). Fine-grained sandstones formed both in floodplain conditions and in small rivers and tributaries of large rivers lays in this area. Sandstones of the basal formation with an increased content of siliceous fragments and kaolinite cement have the lowest values of the femic module (FM).

Titanium module (TM) depends on the composition of rocks in the provenance area and on the dynamics of the sedimentation environment, leading to the sorting of titanium-containing minerals and clay matter. The correlation between the values of hydrolyzate and titanium module confirms the presence of a relationship with dynamic facies of sedimentogenesis (Fig. 6).

Accumulation of titanium-bearing heavy accessories occurred in sandy deposits; a natural increase in the values of titanium module, as well as iron in the series of alluvium «mountain — mountain and plain — plain» is ob-

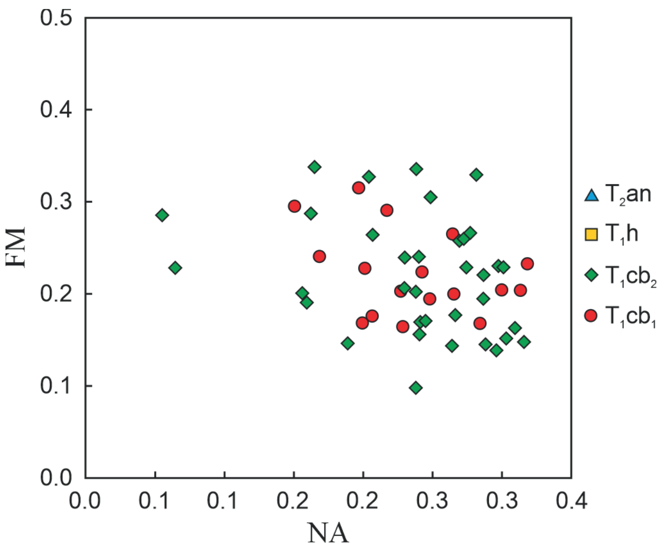

Fig. 5. The values of the femic module (FM) of more than 0.1 is typical for the volcanoclastic graywacke: NA — normalized alkalinity [23]. T_1cb_1 — Lower Triassic Lower Charkabozhskaya subsuite; T_1cb_2 — Upper Charkabozhskaya subsuite; T_1h Lower Triassic Kharaleyskaya suite; T_2an — Middle Triassic Anguranskaya suite

Рис. 5. Значения фемического модуля (FM): NA — нормированная щелочность [23]. T_1cb_1 — нижнечаркабожская подсвита нижнего триаса; T_1cb_2 — верхнечаркабожская подсвита нижнего триаса; T_1h харалейская свита нижнего триаса; T_2an — ангуранская свита среднего триаса

served. The content of iron-titanium concentrate rises, as well as the ratio of «feldspar/mica», due to the washing of light mica from the sands resulted from increasing dynamic sorting of deposition. Point bar sandstones are also characterized by high values of titanium module.

The determination of the geodynamic settings of sedimentation by the lithochemical parameters of clastic rocks is one of the most important issues, a lot of research have been devoted to this issue [2.3.5.17.18.19]. We used the parameters Fe_2O_3+MgO, TiO_2, Al_2O_3/SiO_2, K_2O/Na_2O, Al_2O_3/(CaO+Na_2O) and diagrams of M.R. Bhatia for terrigenous deposits to identify the tectonic setting of the formation of Lower Triassic deposits. The studied sandstones are characterized by the following parameters: Fe_2O_3+MgO vary from 7.2 to 15 with an average of 9.4; TiO_2 values vary within 0.5–1.1 with an average of 0.8. The K_2O/Na_2O values are 0.5–2.4 with an average of 1.06. The sandstones of the Lower Charkabozhskaya subsuite fall mainly into the field of both continental island arcs and active continental margins. The second group of sandstones belonging to the Upper Charkabozhskaya subsuite is concentrated in a cloud of oceanic island arcs.

The location of figurative points on diagrams by V. S. Erofeev and Yu. G. Tsekhovsky [4], as well as by L. Sattner and P. Dutta [18], confirm that the sedimentation took place in an arid climate (Fig. 8).

The best results to characterize tectonic conditions of feeding province for the Triassic graywackes were obtained by the Cronenberg and Maynard diagrams [9.10]. The figurative points of the sandstone composition fall into the field of the passive continental margin (Fig. 8).

Figurative points of sandstones belonging to the Upper Charkabozhskaya subformation fall into the field of Oceanic Island Arcs on the diagrams of M.R. Bhatia (Fe_2O_3+MgO)/SiO_2 and (Fe_2O_3+MgO)/Al_2O_3/SiO_2. The sandstones belonging to the Lower Charkabozhskaya subsuite tend to clusters of the Continental Island Arc and Active Continental Margin on this diagram.

As for the diagrams of Maynard and Walloni, as well as Roser and Korsch, the figurative points of sandstones are in the clusters of Continental Island Arc and Active Continental Margin (Fig. 9).

Due to the high mobility of K_20 and Na_2O, in the (Fe_2O_3+MgO)/K_20/Na_2O Bhatia diagrams, the figurative points of sandstones disintegrate and practically do not fall into any of the fields.

It can be assumed that Pay-Khoy was the provenance area in the Early Triassic. The geodynamic processes of

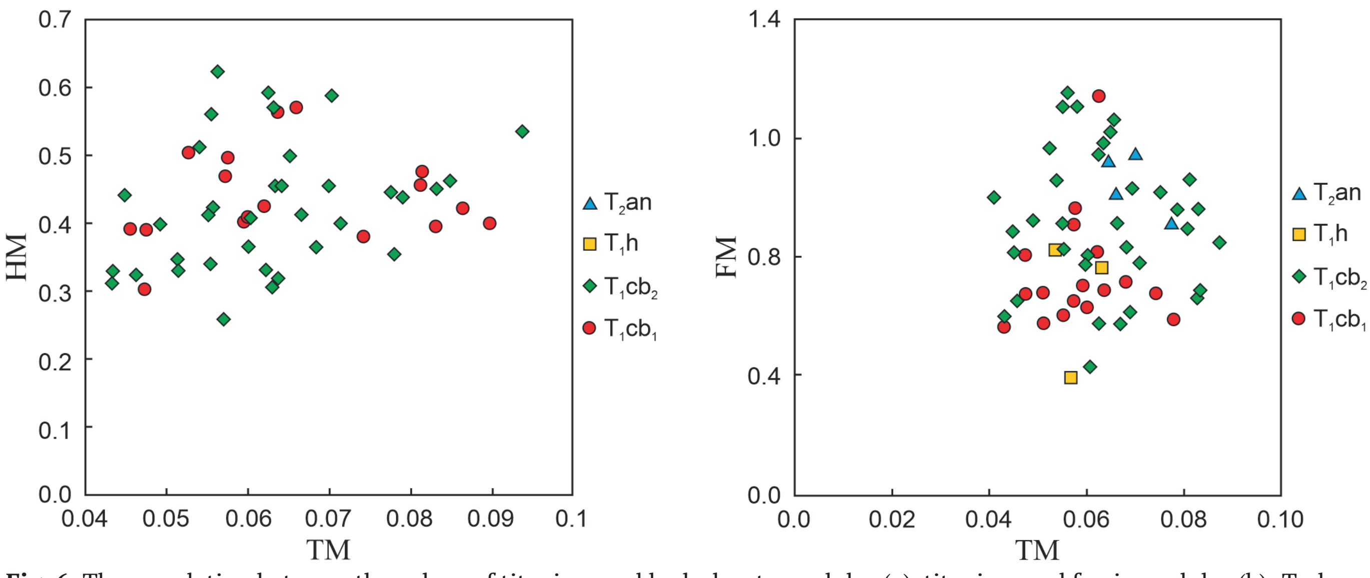

Fig. 6. The correlation between the values of titanium and hydrolyzate modules (a), titanium and femic modules (b): T_1cb_1 — Lower Triassic Lower Charkabozhskaya subsuite; T_1cb_2 — Upper Charkabozhskaya subsuite; T_1h — Lower Triassic Kharaleyskaya suite; T_2an — Middle Triassic Anguranskaya suite

Рис. 6. Положение гидролизатного и титанового модулей: T_1cb_1 — нижнечаркабожская подсвита нижнего триаса; T_1cb_2 — верхнечаркабожская подсвита нижнего триаса; T_1h — харалейская свита нижнего триаса; T_2an — ангуранская свита среднего триаса

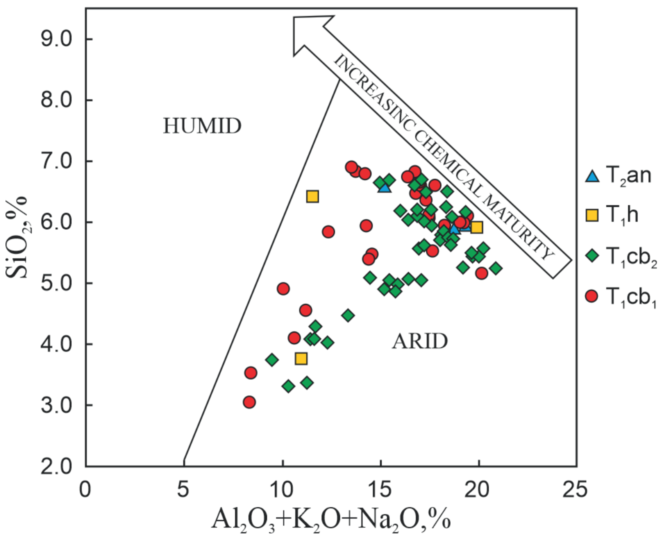

Fig. 7. Chemical maturity trend as a function of climate for the Lower Triassic sandstones expressed as a function of percent SiO_2 and total percent $Al_2O_3+K_2O+Na_2O$

Рис. 7. График зависимости химической зрелости от климата для нижнетриасовых песчаников, выраженный как функция процентного содержания SiO_2 и общего процентного содержания $Al_2O_3+K_2O+Na_2O$

the Late Paleozoic-Early Mesozoic time led to the collision of the approaching Euroamerican and Siberian paleocontinents, as well as the island-arc terrain located between them [20]. In the Triassic, the underthrusting of the passive margin of Laurasia under the Baidaratskaya island arc and the formation of intense fold-thrust structures of the Paleopaleozoic collisional orogen continued.

Conclusion

1. The Lower Triassic reservoirs have alluvial origin. The morphology of them, the structure of sandy bodies, texture, mineral composition of sandstones are determined by depositional environments inside the river systems.

2. The sedimentation conditions controlled the granulometric composition and roundness of the fragments, the degree of their sorting, respectively, the configuration and sizes of the primary intergranular pores. Post-sedimentary transformations resulted in a change in the primary void space. The processes of compaction, cementation, regeneration contributed to its reduction, and dissolution — to its increase due to the expansion of intergranular and the formation of intragranular micropores of recrystallized clay cement.

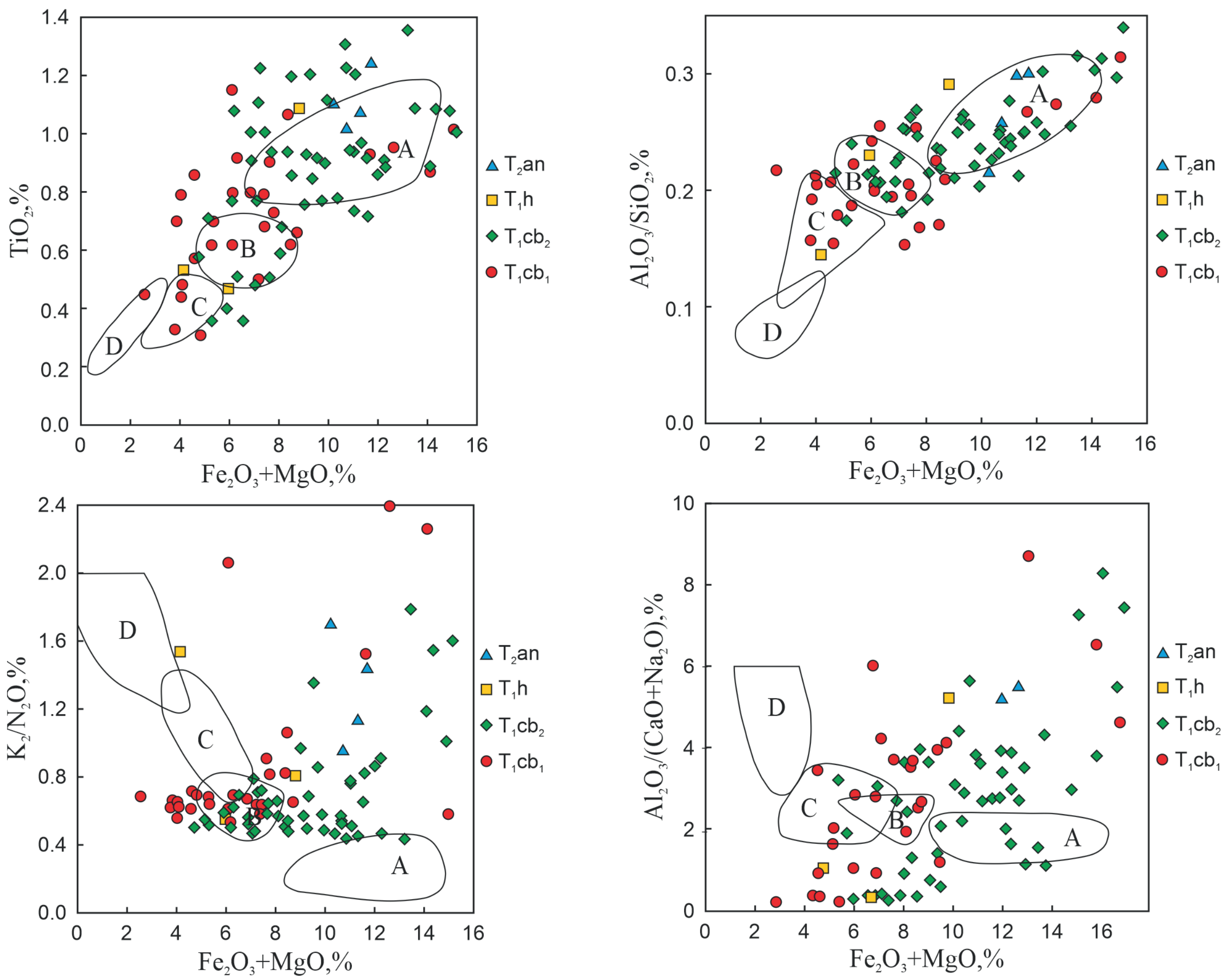

Fig. 8. Diagram of M. R. Bhatia for terrigenous rocks to identify the tectonic setting of the formation of Lower Triassic deposits. A — Oceanic Island Arc. B — Continental Island Arc. C — Active Continental Margin. D — Passive Margin.

Рис. 8. Диаграммы М. Р. Бхатиа состава песчаников различных динамических обстановок. Поля, характеризующие песчаники из различных геодинамических обстановок: A — океанические островные дуги; B — континентальные островные дуги; C — активная континентальная окраина; D — пассивная континентальная окраина

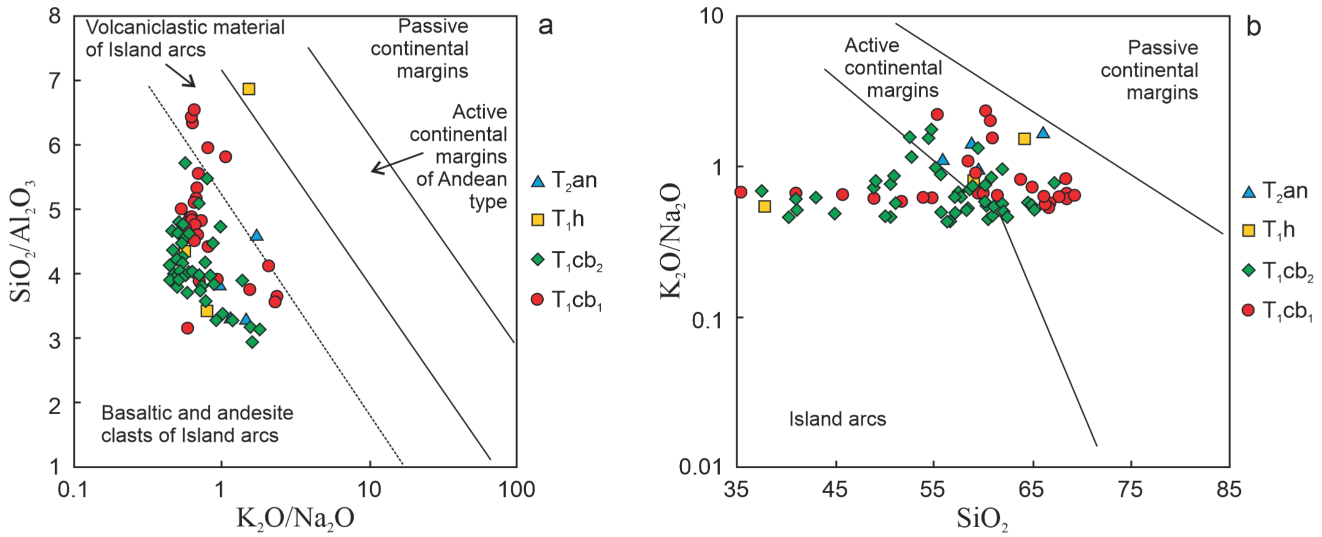

Fig. 9. Diagrams of chemical composition of Lower Triassic deposits from geodynamic situation: a — K_2O/Na_2O-SiO_2/Al_2O_3[10]; b — diagram of B. Roser and R. Korsch [15]

Рис. 9. Диаграммы состава песчаников различных динамических обстановок: a — K_2O/Na_2O-SiO_2/Al_2O_3[10]. В поле базальтовой и андезитовой кластики островных дуг попало подавляющее число точек нижнетриасовых граувакк; b — диаграмма Б. Розера и Р. Корша SiO_2 — K_20/Na_2O

3. The study of the composition of clastic rocks by lithogeochemical methods confirmed that the deposits were formed by the erosion of a collisional orogen and composed of a complex of sedimentary, igneous and metamorphic rocks.

4. Most diagrams can be successfully used for the Lower Triassic graywackes, but to obtain an objective picture, it is necessary to apply complex of methods, including a detailed lithological description, the study of the mineral composition of the clastic part, clay cement diffractometry, and microprobe studies.

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