Науки о Земле Earth sciences

УДК 549+552.323.5

<https://doi.org/10.21440/2307-2091-2020-2-7-19>

Composition of volcanites from pre-Jurassic basement of the Western Siberian megabasin (Lakyuganskaya oil exploration area, YNAD)

Vladimir Sergeevich PONOMAREV*,
Kirill Svyatoslavich IVANOV**,
Yuriy Viktorovich EROKHIN***

The Zavaritsky Institute of Geology and Geochemistry of the Ural Branch of RAS, Ekaterinburg, Russia

Abstract

Relevance of the work. The Western Siberian megabasin is the main source of oil and gas in Russia. Therefore, the study of geological structure and evolution of the development of sedimentary cover rock complexes and the basement of the region is important for estimating the oil and gas potential of this vast territory.

The object of this paper is the mineralogical and petro-geochemical study of volcanites from the pre-Jurassic basement of the Lakyuganskaya area (well no. 101) of the Longyugansk exploration acreage within the territory of the Nadym megadepression of the Western Siberian megabasin.

Scope of work. This work can be useful when constructing geological maps of the basement of the northern part of the Western Siberian Plate.

Results and conclusions. We have studied and described the mineralogy of strongly altered volcanites from the pre-Jurassic basement of the Lakyugansk area (well no. 101) of the Western Siberian Plate. According to chemical composition, the studied volcanites are classified as moderate and high potassic basalts, andesite-basalts and andesites. The rocks were subjected to significant secondary changes in the mineral composition, such as greenschist metamorphism and propylitization. Only titanomagnetite has been preserved from primary minerals in volcanites; all other minerals were subjected to changes. In general, we have determined the following minerals – albite, clinocllore, titanite, calcite, goethite, titanomagnetite (magnetite, ulvospinel), fluorapatite, and rutile. For the first time, ferro-aluminoceladonite (dioctahedral mica) and three relatively rare secondary copper sulfides – spionkopite, yarrowite, and geerite – were identified and described in basalts from the basement of Western Siberia. Sulfide copper mineralization in the studied basalts was due to overlapped propylitization processes. The rocks have features of volcanites of island arcs, as well as evidence of calc-alkali and intraplate basalts. The petrological and geochemical characteristics of the studied volcanites are similar to basalts composing the Koltogorsko-Urengosky rift of the Western Siberian Plate.

Keywords: volcanites, mineralogy, geochemistry, Lakyuganskaya well 101, basement, Western Siberia.

A large number of publications have been devoted to the study of basaltoids from the basement of the Western Siberian Plate [1–18, etc.]. It was found that rocks from the basement of the Western Siberian megabasin were subjected to a multi-stage evolution. Folding and granitization in the Late Paleozoic ended by the beginning of the Triassic period within the territory of the Western Siberian Plate. Later, compression replaced sublatitudinal trending with formation of rifts or grabens as a result [3, 8, 15, etc.]. It is assumed [5 et al.] that superplume was present in the Late Permian Triassic within the territory of Western Siberia; it was in the form of basic and acid magmatism. From another point of view [3, etc.], basalts of the Western Siberian Plate are a single geodynamic type associated with

the main folding in adjacent orogens and called synorogenic. Basaltic Triassic magmatism was accompanied by a powerful bending fold of the region, after which a period of regional subsidence began. It is believed that absolute age of basaltoid magmatism of the basement of the Western Siberian megabasin is 249.4 ± 0.5 Ma [17 et al.]. However, according to recent data [7] – 268.4 ± 7.5 Ma and 268.1 ± 7.5 Ma (Ar–Ar method) for earlier volcanism in the axial rift zones of the Western Siberian Plate. Basalt complexes are overlapped by Jurassic and fresh sediments; these are opened in small amounts by wells drilled to the basement of the Western Siberian Plate. A comprehensive study of drill samples from each well drilled in the complexes of the basement of the Western Siberian megabasin

*p123v@yandex.ru

**ivanovks@igg.uran.ru

<https://orcid.org/0000-0002-8292-4658>

***erokhin-yu@yandex.ru

<https://orcid.org/0000-0002-0577-5898>

Figure 1. Contour well location (Lakyuganskaya no. 101). 1 – settlement; 2 – well.

Рисунок 1. Схематическая карта расположения скважины Лакъюганская № 101. 1 – населенный пункт; 2 – скважина.

is necessary in order to create a database of the structure of this vast region for its further development.

This paper shows the results of the mineralogical and petro-geochemical study of volcanites from the pre-Jurassic basement of the Lakyuganskaya area (well no. 101) of the Longyugansk exploration acreage within the territory of the Nadym megadepression of the Western Siberian megabasin (Fig. 1).

Volcanites from Lakyuganskaya well no. 101 were studied in the depth interval from 4085.3 to 4100 m. The structure of rocks is aphyric, texture is amygdaloid. Mineral composition of rocks: albite $\approx 65\%$, clinoclhor $\approx 20\%$, goethite $\approx 5\%$, ferro-aluminoceladonite $\approx 3\%$, calcite $\approx 3\%$, titanomagnetite (magnetite, ulvospinel) $\approx 3\%$. Accessory mineralization – titanite, apatite, rutile and sulfide mineralization (spionkopite, yarrowite, and geerite).

Rocks are largely composed of plagioclase buried in a chlorite matrix. Goethite veins up to 1 cm thick are observed in the rocks. Amygdales take up to 10% of the rock volume and have a zonal structure; the edge parts are made of chlorite, goethite and calcedony, and the central part is quartz and calcite (Fig. 2). Often a breccia-like structure is observed in amygdales which indicates the tectonization of rocks. Volcanites are broken by resistive fractures (with calcite). Plagioclase is presented by differently oriented elongated grains with a size of mainly 150 microns. The grains have a brownish color. Some grains are polysynthetically twinned according to the albite law. Rarely, in single grains, there are plagioclase phenocrysts up to 1 mm in size in basalts (Fig. 3). They are partially replaced by

calcite. The chemical composition of the mineral corresponds to pure albite (An_{1-3}) (Table 1, an. 1–4).

Chlorite is one of the most common rock minerals. The mineral is brown and green. Grains size is up to 0.15 mm. Chlorite composes interstices of plagioclase crystalloids and forms radial fibrous segregation in amygdales. According to the chemical composition, it corresponds to ferrian and aluminous clinoclhor (Table 1, an. 5–8) with the content of FeO up to 14.85 wt.% and Al_2O_3 up to 23.60 wt.%. Depending on the paragenesis, the composition of chlorite is quite variable, so the Al_2O_3 content varies from 16.05 to 23.60 wt.%, which indicates an increase in the donbassite minimum from 10% to 36%. Clinoclhor contains an admixture of Cr_2O_3 from 0.6 to 4.1 wt.%; such a high content of isomorphic impurity of chromium in the mineral would affect its color, which is not observed. Most likely, this is a mechanical admixture of chromium oxide, which is used in polishing thin sections.

Fluorapatite up to 5 microns in size in the form of single grains of hexagonal section was found in the rock among chlorite aggregate. In addition to chlorite, a large number of small, greenish-brown mica plates up to 100 microns in size are observed in plagioclase interstices. By chemical composition, the mineral is associated with dioctahedral mica – ferro-aluminoceladonite (Table 1, an. 9–12). It is characterized by a high SiO_2 content from 51.91 to 54.51 wt.%. MgO is present in the mineral up to 3.39 wt.% among impurities. High Cr_2O_3 content (up to 2.44 wt.%) in mica; most likely, there is a mechanical admixture of chromium oxide used in polishing thin sections.

Figure 2. Carbonate-chlorite amygdale in basalt. Well Lakyuganskaya 101, depth is 4085.3 m. Without an analyzer. Field of view is 1.5 mm.

Рисунок 2. Карбонат-хлоритовая миндалина в базальте. Скв. Лакъюганская 101, гл. 4085,3 м. Без анализатора. Размер поля зрения 1,5 мм.

Figure 3. Plagioclase phenocryst in andesite-basalt. Well Lakyuganskaya 101, depth is 4089.5 m. Without an analyzer. Field of view is 1.5 mm.

Рисунок 3. Вкрапленник плагиоклаза в андезитобазальте. Скв. Лакъюганская 101, гл. 4089,5 м. Без анализатора. Размер поля зрения 1,5 мм.

Table 1. Chemical composition of the minerals of andesite-basalts (well Lakyuganskaya 101, depth is 4089.5 m), wt.%.

Таблица 1. Химический состав минералов андезитобазальтов (скв. Лакъюганская 101, гл. 4089,5 м), мас. %.

Analysis number	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Total
<i>Albite</i>											
1	68.58	0.03	19.20	N/d	0.20	0.05	0.09	0.51	11.69	0.05	100.40
2	68.94	0.03	19.81	0.06	0.20	N/d	0.06	0.64	10.90	0.22	100.84
3	67.98	—	19.20	0.04	0.09	N/d	N/d	0.14	11.75	0.01	99.21
4	68.46	0.08	19.04	N/d	0.78	0.03	0.19	0.49	10.06	0.61	99.74
<i>Clinocllore</i>											
5	31.16	0.02	17.45	1.30	14.53	1.01	19.56	0.49	0.02	0.09	85.63
6	31.41	0.05	19.55	0.59	14.85	1.00	20.3	0.43	0.04	0.06	88.27
7	32.54	0.04	16.05	4.13	12.92	0.69	17.96	0.65	0.03	0.08	85.09
8	36.95	0.10	23.60	2.27	7.47	0.50	14.80	0.61	0.03	0.40	86.73
<i>Ferro-aluminoceladonite</i>											
9	53.96	0.14	13.06	0.27	14.80	0.08	3.39	0.25	0.02	8.04	94.01
10	51.91	0.55	15.34	2.44	11.05	0.05	3.14	0.70	0.06	8.25	93.49
11	52.09	0.61	15.19	2.10	12.83	0.06	2.99	0.68	0.01	7.65	94.21
12	54.51	0.21	13.56	0.25	14.99	0.08	3.34	0.32	0.03	7.94	95.23
<i>Titanite</i>											
13	30.82	35.32	3.05	N/d	1.01	0.03	0.03	28.72	N/d	N/d	98.98
14	31.33	33.38	4.43	N/d	1.13	0.04	0.37	27.94	N/d	N/d	98.62
15	31.00	33.59	3.73	N/d	1.80	0.09	1.31	27.29	N/d	N/d	98.81
<i>Calcite</i>											
16	—	—	—	—	—	3.09	0.05	61.52	—	—	64.66

Note: hereinafter, the analyses were performed using CAMECA SX 100 microanalyzer (Institute geology and geochemistry Ural Branch of the Russian Academy of Sciences, analyst is I. A. Gottman); n/d — no element content found.

Примечание: здесь и далее анализы выполнены на микроанализаторе CAMECA SX 100 (ИГГ УрО РАН, аналитик И. А. Готтман); н/о – содержание элемента не обнаружено.

At the moment, this is the first find of ferro-aluminoceladonite in rocks of the basement of the Western Siberian Plate. Titanite in the rock occurs in the form of xenomorphic grains up to 100 microns in size. In the chemical composition of the mineral, FeO impurities up to 1.80 wt.% and MgO up to 1.31 wt.% are observed (Table 1, analysis 13–15). Rutile is observed in the form of reddish grains of irregular shape up to 50 microns in size among the chlorite-mica aggregate. Calcite in basalt is found in cracks throughout the rock and minerals curing them. In addition, calcite composes inner parts of amygdalae. In the chemical composition of the mineral, an admixture of MnO is up to 3.02 wt.% (Table 1, an. 16).

The ore mineral in the rock is represented by titanomagnetite, its grains are found across the whole thickness of the rock. The size of individuals of the mineral is up to 80 microns. The shape of grain sections is rectangular, elongated, with skeletal octahedral crystals; xenomorphic and automorphic grains of irregular shape. Often one can see a kind of “crown” of iron hydroxide around crystals – goethite (Fig. 4); and the decay structures of magnetite and ulvospinel are noted in the titanomagnetite matrix itself (Fig. 5). Aciculae of ulvospinel have sizes up to 20 microns with a thickness of about 2 microns. According to the results of microprobe analysis (Table 2, an. 1–8), the content of TiO_2 in magnetite varies from 5.11 to 12.79 wt.%; most likely, this is due to penetration of electron beam into a segregation of thin lamellae of ulvospinel (in addition to magnetite). The low content of TiO_2 (22.16–25.70 wt.%) in ulvospinel (Table 2, an. 9–10) is probably due to the capture of surrounding fine magnetite grains by the electron beam. Al_2O_3 impurities are noted in all titanomagnetite grains studied – up to 0.97 wt.%, V_2O_5 up to 0.79 wt.%, MnO up to 2.35 wt.% and ZnO up to 1.12 wt.%.

As a result of a microprobe study of basalt, three relatively rare copper sulfides were found: spionkopite, yarrowite, and geerite. All of them differ from each other in a different ratio of copper to sulfur content. Spionkopite (Fig. 6) and geerite

were found by us in the form of single grains in interstices of plagioclase crystalloids, as well as in aggregates of chlorite and ferro-aluminoceladonite and in fractures cased with calcite. The mineral has polygonal sections of grains up to 25 microns in size. Yarrowite is found in cased cracks in basalt filled with calcite and chlorite, and also in the form of single grains randomly distributed across the whole thickness of the rock. The grains are elongated and irregular in size up to 10 microns. The chemical composition of copper sulfides and their theoretical compositions are given in Table 3. In all minerals, Fe impurities up to 0.89 wt.% are identified; Pb is up to 0.17 wt.%; Ag is up to 0.1 wt.% and Se is up to 0.12 wt.%. Compositions of minerals are close to theoretical compositions of geerite, spionkopite, and yarrowite.

Yarrowite and spionkopite are secondary copper sulfides that have been first identified in the stratiform copper-ore deposits in the Yarrow Creek and Spionkop Creek areas of Alberta (Canada) together with chalcopyrite, bornite, anilite, djurleite, tennantite and vittekhinite [19]. In the Southern Urals, spionkopite is known in the Karabash copper-ore deposit [20]. In addition, sulfide has been identified in Russia in the ore occurrence Televeem in the Anadyr area (Chukotka), where spionkopite replaces bornite along fractures [21]. Geerite is also a typical secondary copper sulfide identified in samples from DeKalb township (New York State, USA) in association with calcite, green copper, azurite, brochantite, chrysocolla, stibiconite, cervantite, hemimorphite, gray copper ore and chalcopyrite [22]. In our case, copper sulfides were formed as a result of superimposition of basalts; copper sulfides are of secondary origin developing along fractures in chlorite-mica aggregates, where primary copper sulfides, such as chalcopyrite or bornite, were probably replaced, resulting in goethite, spionkopite, geerite and yarrowite.

Volcanites from the Lakyuganskaya 101 well underwent significant secondary changes, such as chloritization and carbonatization (losses due to roasting in rocks from 5.30 to 8.40

Figure 4. Skeletal octahedral crystals of titanomagnetite in andesite-basalt. Well Lakyuganskaya 101, depth is 4089,5 m. BSE-photo. Field of view is 1.5 mm.

Рисунок 4. Скелетные октаэдрические кристаллы титаномагнетита в андезитобазальте. Скв. Лакьюганская 101, гл. 4089,5 м. BSE-фото. Размер поля зрения 1,5 мм.

Figure 5. Magnetite and ulvospinel decay structures in titanomagnetite. Well Lakyuganskaya 101, depth is 4089,5 m. BSE-photo. Field of view is 1.5 mm.

Рисунок 5. Структуры распада магнетита и ульвошпинели в титаномагнетите. Скв. Лакьюганская 101, гл. 4089,5 м. BSE-фото. Размер поля зрения 1,5 мм.

wt.%, table 4). The chemical composition of basalts shows a high content of alumina (Al_2O_3 up to 16.02 wt.%), the studied volcanites belong to rocks of normal alkalinity ($\text{K}_2\text{O} + \text{Na}_2\text{O}$ varies from 2.78 to 4.78 wt.%). According to the K_2O content (K_2O 0.37–1.44 wt.%), the studied basalts are moderately and high potassium rocks. In the TAS classification diagram [23], the Lakyuganskaya 101/4086 sample fell into the field of normal alkalinity, the Lakyuganskaya 101/4089 and Lakyuganskaya 101/4096 samples fell into the andesite basalt field and the Lakyuganskaya 101/4100 sample – into the andesite field (Fig. 7). In volcanites, high contents (ppm) of Ti (up to 7143), V (up to 413), Mn (up to 1975), Sr (up to 508), Zr (up to 173), Ba (up to 277), and Ce (up to 67) are noted. The content of rare-earth elements in rocks is 147–172 ppm (Table 5). The distribution trend of rare-earth elements normalized to chondrite

is close to all volcanites (Fig. 8, a) and is characterized by the predominance of light lanthanides over heavy ones and the presence of a weak negative Europium anomaly. Basalts of oceanic islands have a close distribution of rare-earth elements but in the absence of Europium anomalies. On the spider plot (Fig. 8, b) of rare, trace elements, and rare earth elements normalizing to the primitive mantle, basalts show positive anomalies in lead and negative anomalies in rubidium, barium, niobium, tantalum, strontium, phosphorus, and titanium. On the known discriminatory graphs for volcanites, the studied rocks fall into the field of calc-alkaline basalts (Fig. 9, a, b), as well as tholeiitic (Fig. 10, a) and within-plate basalts (Fig. 10, b). We previously found basalts with similar geochemical characteristics in the Danilovsky graben of the Shaimsky area of the Cisuralian part of Western Siberia; these are also

Figure 6. Spionkopite grains (Spk) in basalt from Lakyuganskaya 101 well, depth is 4085.3 m.
Рисунок 6. Зерна спионкопита (Spk) в базальте из скважины Лакъюганская 101, глубина 4085,3 м.

Table 2. Composition of titanomagnetite from andesite-basalt (well Lakyuganskaya 101, depth is 4089,5 m), wt.%.
Таблица 2. Состав титаномagnetита из андезитобазальта (скв. Лакъюганская 101, гл. 4089,5 м), мас.%.

Analysis number	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	V ₂ O ₃	FeO*	MnO	MgO	ZnO	Total
Magnetite										
1	0.25	6.67	0.19	0.02	0.35	81.81	0.20	0.23	0.02	89.74
2	0.90	7.22	0.13	0.10	0.06	78.34	2.35	0.00	1.12	90.22
3	0.35	5.18	0.53	0.08	0.39	82.10	0.12	0.06	0.04	88.85
4	0.47	5.98	0.47	0.04	0.52	81.50	0.15	0.09	0.09	89.31
5	0.38	5.88	0.44	0.09	0.74	82.80	0.13	0.11	0.00	90.57
6	0.33	5.11	0.23	0.03	0.10	84.32	0.12	0.20	0.00	90.44
7	0.87	9.48	0.56	0.03	0.13	77.69	0.46	0.48	0.06	89.76
8	0.06	12.79	0.32	0.00	0.17	75.81	0.40	0.89	0.02	90.46
Ulvospinel										
9	0.19	22.16	0.21	0.01	0.24	64.27	0.35	0.51	0.08	88.02
10	0.19	25.70	0.97	0.02	0.79	63.12	0.57	0.52	0.09	91.97

no.te: FeO* = FeO + Fe₂O₃.

**Table 3. Composition of sulfides from basalts (well Lakyuganskaya 101, depth is 4085,3 m), wt.%.
Таблица 3. Состав сульфидов из базальтов (скв. Лакъюганская 101, гл. 4085,3 м), мас.%.**

Analysis number	Cu	Fe	Mn	Pb	As	Ag	S	Se	Total
<i>Yarrowite</i>									
1	69.76	0.51	N/d	0.09	0.01	N/d	28.45	0.12	98.94
2	70.63	0.53	N/d	0.04	0.07	N/d	28.42	0.07	99.76
3	71.43	0.51	N/d	0.08	N/d	0.09	27.08	0.09	99.28
4*	69.03	–	–	–	–	–	30.97	–	100.00
<i>Spionkopite</i>									
5	73.95	0.59	N/d	0.17	N/d	0.05	24.35	0.10	99.21
6	73.85	0.69	N/d	0.06	N/d	0.03	25.15	0.04	99.82
7	73.82	0.89	N/d	N/d	0.04	0.04	25.07	0.06	99.92
8*	73.51	–	–	–	–	–	26.49	–	100.00
<i>Geerite</i>									
9	75.00	0.60	N/d	0.03	N/d	0.09	23.18	0.08	98.98
10	75.44	0.52	N/d	0.09	0.04	N/d	23.63	0.08	99.80
11	75.65	0.48	0.01	0.10	0.02	N/d	23.90	0.11	100.27
12	75.28	0.66	0.01	0.03	N/d	0.04	23.72	0.07	99.81
13	75.32	0.42	N/d	N/d	0.02	0.04	23.45	0.10	99.35
14	75.53	0.70	0.02	0.14	0.04	N/d	23.45	0.07	99.94
15	76.06	0.43	0.02	0.12	0.04	0.10	22.95	0.09	99.80
16*	76.02	–	–	–	–	–	23.98	–	100.00

Note: * – theoretical compositions of sulphide minerals.

Примечание: * – теоретические составы сульфидных минералов.

**Table 4. Chemical composition of rocks from the well Lakyuganskaya 101, wt.%.
Таблица 4. Химический состав пород из скважины Лакъюганская 101, мас.%.**

Elements	1	2	3	4
P ₂ O ₅	0.27	0.34	0.28	0.33
SiO ₂	45.11	50.35	48.34	56.85
TiO ₂	1.13	1.36	1.27	1.23
Al ₂ O ₃	13.50	15.58	13.79	16.02
Fe ₂ O ₃	13.23	10.75	15.76	6.73
MgO	6.61	5.65	5.65	4.14
FeO	2.10	1.10	0.70	0.40
MnO	0.34	0.16	0.18	0.13
CaO	6.50	3.76	4.10	4.03
Na ₂ O	2.41	2.99	2.41	3.43
K ₂ O	0.37	1.44	1.33	1.35
Losses due to roasting	8.40	6.50	6.10	5.30
Total	99.95	99.98	99.93	99.94

Note: 1 – Lakyuganskaya 101/4086, basalt; 2 – Lakyuganskaya 101/4089, andesite-basalt; 3 – Lakyuganskaya 101/4096, andesite-basalt; 4 – Lakyuganskaya 101/4100, andesite.

Примечание: 1 – Лакъюганская 101/4086, базальт; 2 – Лакъюганская 101/4089, андезитобазальт; 3 – Лакъюганская 101/4096, андезитобазальт; 4 – Лакъюганская 101/4100, андезит.

K₂O + Na₂O

Figure 7. TAS diagram for volcanites from Lakyuganskaya 101 well [23]. 1 – Lakyuganskaya 101/4096, andesite-basalt; 2 – Lakyuganskaya 101/4100, andesite; 3 – Lakyuganskaya 101/4086, basalt; 4 – Lakyuganskaya 101/4089, andesite-basalt.

Рисунок 7. Диаграмма TAS для вулканитов из скважины Лакьюганская 101 [23]. 1 – Лакьюганская 101/4096, андезитобазальт; 2 – Лакьюганская 101/4100, андезит; 3 – Лакьюганская 101/4086, базальт; 4 – Лакьюганская 101/4089, андезитобазальт.

Figure 8. Distribution plots of rare-earth elements normalized to chondrite (a) [24], and rare, trace elements and rare-earth elements normalized to primitive mantle (b) [24] in the from Lakyuganskaya 101 well.

Рисунок 8. Диаграммы распределения редкоземельных элементов, нормированных на хондрит (а) [24], и редких, рассеянных и редкоземельных элементов, нормированных на примитивную мантию (б) [24], в породах из скважины Лакьюганская 101.

Table 5. Trace element composition of volcanites from the well Lakyuganskaya 101, ppm.
Таблица 5. Микроэлементный состав вулканитов из скважины Лакъюганская 101, г/г.

Elements	Lakyuganskaya 101/4086	Lakyuganskaya 101/4089	Lakyuganskaya 101/4096	Lakyuganskaya 101/4100	Elements	Lakyuganskaya 101/4086	Lakyuganskaya 101/4089	Lakyuganskaya 101/4096	Lakyuganskaya 101/4100
Li	19.74	18.87	17.16	13.01	Sb	3.84	4.40	3.88	3.80
Be	0.76	1.05	1.00	1.00	Cs	1.34	3.97	2.58	2.19
Sc	33.24	40.16	38.81	37.84	Ba	277.15	198.49	264.54	272.87
Ti	6079.54	7142.83	6833.29	6731.11	La	20.53	23.81	22.86	18.80
V	256.78	220.02	412.90	172.79	Ce	55.98	67.20	62.28	57.51
Cr	4.46	4.53	4.19	4.20	Pr	6.77	8.08	7.45	6.99
Mn	1974.50	972.58	1209.36	796.29	Nd	31.04	36.03	34.08	29.80
Co	31.48	27.04	33.53	22.64	Sm	6.92	7.72	7.44	6.73
Ni	9.30	8.47	9.75	5.98	Eu	1.48	1.67	1.68	1.94
Cu	26.58	21.65	27.11	53.42	Gd	6.17	7.05	6.75	6.79
Zn	68.32	65.47	81.52	56.08	Tb	0.92	1.06	1.00	1.01
Ga	16.49	19.83	17.95	13.89	Dy	6.33	7.10	6.79	6.67
Ge	1.41	1.41	1.33	1.42	Ho	1.33	1.51	1.45	1.39
As	7.59	10.57	12.31	21.47	Er	4.02	4.56	4.40	4.17
Se	0.96	0.94	0.97	0.94	Tm	0.60	0.67	0.66	0.61
Rb	11.46	52.74	50.40	40.96	Yb	3.86	4.40	4.28	3.94
Sr	236.79	316.41	473.69	508.36	Lu	0.60	0.68	0.66	0.59
Y	32.29	35.76	34.19	33.86	Hf	4.49	5.03	4.90	4.85
Zr	155.18	173.21	166.05	171.52	Ta	0.43	0.50	0.49	0.48
Nb	6.24	7.07	6.71	6.82	W	3.45	1.86	6.22	7.90
Mo	0.87	0.77	1.33	3.16	Tl	0.06	0.29	0.25	0.22
Ag	0.21	0.24	0.23	0.25	Pb	8.48	7.31	7.86	4.97
Cd	0.05	0.05	0.06	0.06	Bi	0.05	0.02	0.03	0.02
Sn	1.29	1.39	1.43	1.59	Th	3.57	4.09	3.85	3.77
					U	1.70	1.71	1.68	1.81

close to the basalts and dolerites of the Western Tarkosalinsky (Purovsky region, Yamalo-Nenets Autonomous District [25]) and Verkhnekhudosey (Krasnoselkupsky area, Yamal-Nenets Autonomous District [26]) areas of Western Siberia. Permian-Triassic volcanites of the Koltogorsko-Urengoy sky rift in Western Siberia have similar features [13]. Investigation of the geological situation shows that the studied volcanites were formed during continental genesis of rifts.

Thus, we studied and described the mineralogy of strongly altered volcanites from the pre-Jurassic basement of the Lakyugansk area (well no. 101) in the Yamalo-Nenets Autonomous District of the Western Siberian Plate. According to chemical composition, the studied volcanites are classified as moderate and high potassic basalts, andesite-basalts and andesites. The rocks were subjected to significant secondary changes in the mineral composition, such as greenschist

Figure 9. Discrimination plots $Zr-Ti/100-Y \cdot 3$ (a) and $Zr-Ti/100-Sr/2$ (b) [27] for volcanites from Lakyuganskaya 101 well. MORB - Mid-ocean ridge basalts.

Рисунок 9. Дискриминационные диаграммы $Zr-Ti/100-Y \cdot 3$ (a) и $Zr-Ti/100-Sr/2$ (б) [27] для вулканитов из скважины Лакъюганская 101. MORB - базальты СОХ.

Figure 10. Discrimination plots $TiO_2-Zr/(P_2O_5 \cdot 10^4)$ (a) [28] and $Zr/Y-Zr$ (b) [29] for volcanites from Lakyuganskaya 101 well. E-MORB – basalts enriched with impurities, WPB – within-plate basalts.

Рисунок 10. Дискриминационные диаграммы $TiO_2-Zr/(P_2O_5 \cdot 10^4)$ (a) [28] и $Zr/Y-Zr$ (б) [29] для вулканитов из скважины Лакъюганская 101. E-MORB – базальты СОХ обогащенного типа, WPB – внутриплитные базальты.

metamorphism and propylitization. Only titanomagnetite has been preserved from primary minerals in volcanites; all other minerals were subjected to changes. In general, we have determined the following minerals – albite, clinocllore, titanite, calcite, goethite, titanomagnetite (magnetite, ulvospinel), fluorapatite and rutile. For the first time, ferro-aluminoceladonite (dioctahedral mica) and three relatively rare secondary copper sulfides – spionkopite, yarrowite, and

geerite – were identified and described in basalts from the basement of Western Siberia. Sulfide copper mineralization in the studied basalts was due to overlapped propylitization processes. The rocks have features of volcanites of island arcs, as well as evidence of calc-alkali and within-plate basalts. The petrological and geochemical characteristics of the studied volcanites are close to the basalts of the Koltogorsko-Urengoy'sky rift of the Western Siberian Plate.

The research was carried out with the support of the Russian Foundation for Basic Research (project no. 18-05-70016).

REFERENCES

1. Almkhamedov A. I., Medvedev A. Ya., Kirda N. P., Baturina T. P. 1998, Triassic volcanic complex of Western Siberia. *Doklady Akademii nauk* [Doklady Earth Sciences], vol. 362, no. 3, pp. 372–377. (In Russ.)
2. Bochkarev V. S. 2001, *Vulkanogennyye obrazovaniya triasa Zapadnoy Sibiri* [Volcanogenic formations of the Triassic of Western Siberia]. Triassic of Western Siberia. no.vosibirsk, pp. 70–79.
3. Bochkarev V. S., Brekhuntsov A. M., Deshchenya N. P. 2005, *Geodinamicheskiye obstanovki formirovaniya Zapadno-Sibirskogo basseyna i yego neftegazonosnost'* [Geodynamic conditions of the formation of the West Siberian basin and its oil and gas potential]. Tectonics of the Earth's crust and mantle. Proceedings of the XXXVIII Tectonic Meeting. Moscow, vol. 1, pp. 71–74.
4. Kontorovich A. E., Nesterov I. I., Salmanov F. K., Surkov V. S., Trofimuk A. A., Ervier Yu. G. 1975, *Geologiya nefti i gaza Zapadnoy Sibiri* [Geology of oil and gas of Western Siberia]. Moscow, 679 p.
5. Dobretsov N. L. 1997, Permian-Triassic magmatism and sedimentation in Eurasia as a reflection of superplume. *Doklady Akademii nauk* [Doklady Earth Sciences], vol. 354, no. 2, pp. 220–223. (In Russ.)
6. Ivanov K. P., Ivanov K. S., Fedorov Yu. N. 2007, *Geokhimiya triasovykh vulkanitov Zapadno-Sibirskoy plity* [Geochemistry of Triassic volcanic rocks of the West Siberian Plate (using the Turin series as an example). Geodynamics, magmatism, metamorphism and ore formation. Ekaterinburg, pp. 766–790.
7. Ivanov K. S., Erokhin Yu. V. 2019, On the emplacement time of the system of Triassic rifts in Western Siberia. *Doklady Akademii nauk* [Doklady Earth Sciences], vol. 486, no. 1, pp. 88–92. (In Russ.)
8. Kulikov P. K., Belousov A. P., Latypov A. A. 1972, West-Siberian Triassic Rift System. *Geotektonika* [Geotectonics], no. 6, pp. 79–87. (In Russ.)
9. Kremenetsky A. A., Gladkikh V. S. 1997, Low potassium tholeiitic basalts are an indicator of the evolution of paleogeodynamic conditions and the forecast of hydrocarbon raw materials (according to the Tyumen ultra-deep well SG-6). *Geokhimiya* [Geochemistry], no. 6, pp. 609–617. (In Russ.)
10. Medvedev A. Ya., Almkhamedov A. I., Kirda N. P. 2003, Geochemistry of Permo-Triassic volcanites of Western Siberia. *Geologiya i geofizika* [Geology and Geophysics], vol. 44, no. 1-2, pp. 86–100. (In Russ.)
11. Kontorovich A. E., Surkov V. S., Trofimuk A. A. et al. 1994, *Neftegazonosnyye basseyny i regiony Sibiri* [Oil and gas basins and regions of Siberia], Issue 2. Western Siberian basin. no.vosibirsk, 201 p.
12. Simonov V. A., Klets A. G., Stupakov S. I. 2008, *Bazaltovyye komplekсы v fundamente Zapadno-Sibirskogo osadochnogo basseyna* [Basalt complexes in the basement of the Western Siberian sedimentary basin] (data for the Mayzasskaya-1 parametric well). Basement, framing structures of the Western Siberian Mesozoic-Cenozoic sedimentary basin, their geodynamic evolution and oil and gas problems. All-Russian Scientific Conference. Tyumen; no.vosibirsk, pp. 197–201.
13. Saraev S. V., Baturina T. P., Ponomarchuk V. A., Travin A. V. 2009, Permo-Triassic volcanites of the Koltogorsko-Urengoy'sky rift of the Western Siberian geosyncline. *Geologiya i geofizika* [Geology and geophysics], vol. 50, no. 1, pp. 4–20. (In Russ.)
14. Simonov V. A., Klets A. G., Kovyazin S. V., Stupakov S. I., Travin A. V. 2010, Physical and chemical conditions of early plume magmatism of Western Siberia. *Geologiya i geofizika* [Geology and geophysics], vol. 51, no. 9, pp. 1277–1297. (In Russ.)
15. Surkov V. S., Trofimuk A. A., Zhero O. G., Kontorovich A. E., Smirnov L. V. 1982, Triassic rift system of the Western Siberian Plate, its influence on the structure and oil and gas potential of the platform Mesozoic-Cenozoic cover. *Geologiya i geofizika* [Geology and geophysics], no. 8, pp. 3–15. (In Russ.)
16. Fedorov Yu. N. 2004, *Geologicheskoye stroeniye i perspektivy neftegazonosnosti oblasti sochleneniya Pripolyarnogo Urala i Zapadno-Sibirskogo megabasseyna* [Geological structure and oil and gas prospects of interareas of the Nether-Polar Urals and the Western Siberian megabasin], PhD thesis. Ekaterinburg, 28 p.
17. Reichow M. K., Saunders A. D., White R. W., Pringle M., Al'mukhamedov A. I., Medvedev A. Ya., Kirda N. P. 2002, $^{40}\text{Ar}/^{39}\text{Ar}$ dates from the West Siberian Basin: Siberian flood basalt province doubled. *Science*, vol. 296, pp. 1846–1849. <https://doi.org/10.1126/science.1071671>
18. Reichow M. K., Saunders A. D., White R. V., Al'mukhamedov A. I., Medvedev A. Ya. 2005, Geochemistry and petrogenesis of basalts from the West Siberian Basin: an extension of the Permo-Triassic Siberian Traps, Russia. *Lithos*, vol. 79, pp. 425–452. <https://doi.org/10.1016/j.lithos.2004.09.011>
19. Goble R. J. 1980, Copper sulfides from Alberta: yarrowite Cu_9S_8 and spionkopite $\text{Cu}_{39}\text{S}_{28}$. *Canadian Mineralogist*, vol. 18, pp. 511–518.
20. Spiridonov E. M., Pletnev P. A., Perelygina E. V., Rapoport M. S. 1997, *Geologiya i mineralogiya mestorozhdeniya medistogo zolota Zolotaya Gora (Karabashskoye), Sredniy Ural* [Geology and mineralogy of the copper gold deposit Zolotaya Gora (Karabash), Middle Urals]. Moscow, 192 p.
21. Vlasov E. A., Prokofiev V. Yu., Nikolaev Yu. N., Kalko I. A. 2016, A new find of gold-telluride mineralization in Chukotka: mineralogy and conditions for the formation of ore occurrence Televeem. *Rudy i metally* [Ore and metals], no. 4, pp. 48–59. (In Russ.)
22. Goble R. J., Robinson G. 1980, Geerite, Cu_{160}S , a new copper sulfide from DeKalb Township, New York. *Canadian Mineralogist*, vol. 18, pp. 519–523.
23. Le Bas M. J., Le Maitre R. W., Streckeisen A., Zanettin B. 1986, A chemical classification of volcanic rocks based on the total alkalisilica diagram. *Journal of Petrology*, vol. 27, pp. 745–750. <https://doi.org/10.1093/petrology/27.3.745>
24. Sun S. S., McDonough W. F. 1989, Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In: *Magmatism in Ocean Basins*. London, Geol. Soc. Spec. Publ., pp. 313–345. <https://doi.org/10.1144/GSL.SP.1989.042.01.19>
25. Ponomarev V. S., Erokhin Yu. V., Ivanov K. S. 2017, Composition of basalts from the pre-Jurassic basement of Western Siberia (West-Tarkosalinskaya area, Yamalo-Nenets autonomous district). *News of the Ural State Mining University*, issue 1 (45), pp. 14–18. <https://doi.org/10.21440/2307-2091-2017-1-14-18>
26. Ponomarev V. S., Ivanov K. S., Erokhin Yu. V. 2019, Composition of basalts and dolerites from the pre-Jurassic basement of the West Siberian Plate (Verkhnekhudoseyskaya area, Yamalo-Nenets Autonomous District). *Izvestiya Vuzov. Severo-Kavkazskii Region. Yestestvennyye nauki*. [Bulletin of higher education institutes. no.rth Caucasus region. Natural sciences], no. 3, pp. 62–69. (In Russ.)

27. Pearce J. A., Cann J. R. 1973, Tectonic setting of basic volcanic rocks determined using trace element analyses. *Earth and Planetary Science Letters*, vol. 19, pp. 290–300. [https://doi.org/10.1016/0012-821X\(73\)90129-5](https://doi.org/10.1016/0012-821X(73)90129-5)
28. Winchester J. A., Floyd P. A. 1977, Geochemical discrimination of different magma series and their differentiation products using immobile elements. *Chemical Geology*, vol. 20, pp. 325–343. [https://doi.org/10.1016/0009-2541\(77\)90057-2](https://doi.org/10.1016/0009-2541(77)90057-2)
29. Pearce J. A., norry M. J. 1979, Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks. *Contributions to Mineralogy and Petrology*, vol. 69, pp. 33–47.

The article was received on March 30, 2020

Вещественный состав вулканитов доюрского основания Западно-Сибирского мегабассейна (Лакъюганская нефтеразведочная площадь, ЯНАО)

Владимир Сергеевич ПОНОМАРЕВ*,
Кирилл Святославич ИВАНОВ**,
Юрий Викторович ЕРОХИН***

Институт геологии и геохимии им. А. Н. Заварицкого УрО РАН, Россия, Екатеринбург

Аннотация

Актуальность работы. Западно-Сибирский мегабассейн – главный источник нефти и газа России, поэтому изучение геологического строения и эволюции развития комплексов пород осадочного чехла и фундамента региона важно для оценки нефтегазоносности этой огромной территории.

Целью работы является минералогическое и петролого-геохимическое исследование вулканитов из доюрского фундамента Лакъюганской площади (скважина № 101) Лонгъюганского поискового участка, расположенной на территории Надымской мегаблоков Западно-Сибирского мегабассейна.

Область применения работы. Настоящая работа может быть полезна при построении геологических карт фундамента северной части Западно-Сибирской плиты.

Результаты работы и выводы. Нами изучена и описана минералогия сильно измененных вулканитов из доюрского фундамента Лакъюганской площади (скважина № 101) Западно-Сибирской плиты. По химическому составу исследуемые вулканиты относятся к умеренно- и высококалиевым базальтам, андезитобазальтам и андезитам. Породы претерпели значительные вторичные изменения минерального состава, такие как зеленосланцевый метаморфизм и пропилитизация. Из первичных минералов в вулканитах сохранился только титаномagnetит, все остальные минералы подверглись вторичным изменениям. В целом нами установлены следующие минералы: альбит, клинохлор, титанит, кальцит, гетит, титаномagnetит (magnetит, ульвошпинель), фторапатит и рутил. Впервые в базальтах из фундамента Западной Сибири установлены и описаны ферроалюминоселадонит (диоктаэдрическая слюда) и три относительно редких вторичных сульфида меди – спинокопит, ярроут, джирит. Сульфидная медная минерализация в исследуемых базальтах образовалась за счет наложенных процессов пропилитизации. Породы обладают чертами вулканитов островных дуг, а также признаками известково-щелочных и внутриплитных базальтов. Отмечена близость петролого-геохимических характеристик исследуемых вулканитов и базальтов, слагающих Колтогорско-Уренгойский рифт Западно-Сибирской плиты.

Ключевые слова: вулканические породы, минералогия, геохимия, скважина Лакъюганская 101, фундамент, Западная Сибирь.

Исследования проведены при поддержке РФФИ (проект № 18-05-70016).

ЛИТЕРАТУРА

1. Альмухамедов А. И., Медведев А. Я., Кирда Н. П., Батурина Т. П. Триасовый вулканогенный комплекс Западной Сибири // Докл. РАН... 1998. Т. 362, № 3. С. 372–377.
2. Бочкарев В. С. Вулканогенные образования триаса Западной Сибири // Триас Западной Сибири. Новосибирск: СНИИГТИМС, 2001. С. 70–79.
3. Бочкарев В. С., Брехунцов А. М., Дещеня Н. П. Геодинамические обстановки формирования Западно-Сибирского бассейна и его нефтегазоносность // Тектоника земной коры и мантии: материалы XXXVIII Тектонич. совещ. М.: ГЕОС, 2005. Т. 1. С. 71–74.
4. Конторович А. Э., Нестеров И. И., Салманов Ф. К., Сурков В. С., Трофимук А. А., Эрвье Ю. Г. Геология нефти и газа Западной Сибири. М.: Недра, 1975. 679 с.
5. Добрецов Н. Л. Пермско-триасовые магматизм и осадконакопление в Евразии как отражение суперплюма // Докл. РАН..., 1997. Т. 354, № 2. С. 220–223.
6. Иванов К. П., Иванов К. С., Федоров Ю. Н. Геохимия триасовых вулканитов Западно-Сибирской плиты (на примере туринской серии) // Геодинамика, магматизм, метаморфизм и рудообразование. Екатеринбург: ИГГ УрО РАН, 2007. С. 766–790.
7. Иванов К. С., Ерохин Ю. В. О времени заложения системы триасовых рифтов Западной Сибири // Докл. РАН..., 2019. Т. 486, № 1. С. 88–92.
8. Куликов П. К., Белоусов А. П., Латыпов А. А. Западно-Сибирская триасовая рифтовая система // Геотектоника. 1972. № 6. С. 79–87.
9. Кременецкий А. А., Гладких В. С. Низкокалиевые толеитовые базальты – индикатор эволюции палеогеодинамических обстановок и прогноза углеводородного сырья (по данным Тюменской сверхглубокой скв. СГ-6) // Геохимия. 1997. № 6. С. 609–617.
10. Медведев А. Я., Альмухамедов А. И., Кирда Н. П. Геохимия пермтриасовых вулканитов Западной Сибири // Геология и геофизика. 2003. Т. 44, № 1-2. С. 86–100.
11. Конторович А. Э., Сурков В. С., Трофимук А. А. и др. Нефтегазоносные бассейны и регионы Сибири. Вып. 2. Западно-Сибирский бассейн. Новосибирск: ОИГГ СО РАН, 1994. 201 с.

✉ p123v@yandex.ru

*ivanovks@igg.uran.ru

<https://orcid.org/0000-0002-8292-4658>

***erokhin-yu@yandex.ru

<https://orcid.org/0000-0002-0577-5898>

12. Симонов В. А., Клец А. Г., Ступаков С. И. Базальтовые комплексы в фундаменте Западно-Сибирского осадочного бассейна (данные по параметрической скважине Майзасская-1) // Фундамент, структуры обрамления Западно-Сибирского мезозойско-кайнозойского осадочного бассейна, их геодинамическая эволюция и проблемы нефтегазоносности: Всерос. науч. конф. Тюмень; Новосибирск: ИНГГ СО РАН, 2008. С. 197–201.
13. Сараев С. В., Батурина Т. П., Пономарчук В. А., Травин А. В. Пермотриасовые вулканиты Колтогорско-Уренгойского рифта Западно-Сибирской геосинеклизы // Геология и геофизика. 2009. Т. 50, № 1. С. 4–20.
14. Симонов В. А., Клец А. Г., Ковязин С. В., Ступаков С. И., Травин А. В. Физико-химические условия раннего плюмового магматизма Западной Сибири // Геология и геофизика. 2010. Т. 51, № 9. С. 1277–1297.
15. Сурков В. С., Трофимук А. А., Жеро О. Г., Контарович А. Э., Смирнов Л. В. Триасовая рифтовая система Западно-Сибирской плиты, ее влияние на структуру и нефтегазоносность платформенного мезозойско-кайнозойского чехла // Геология и геофизика. 1982. № 8. С. 3–15.
16. Федоров Ю. Н. Геологическое строение и перспективы нефтегазоносности области сочленения Приполярного Урала и Западно-Сибирского мегабассейна: автореф. дис. ... канд. геол.-минерал. наук. Екатеринбург: ИГГ УрО РАН, 2004. 28 с.
17. Reichow M. K., Saunders A. D., White R. W., Pringle M., Al'mukhamedov A. I., Medvedev A. Ya., Kirde N. P. $^{40}\text{Ar}/^{39}\text{Ar}$ dates from the West Siberian Basin: Siberian flood basalt province doubled // Science. 2002. Vol. 296. P. 1846–1849. <https://doi.org/10.1126/science.1071671>
18. Reichow M. K., Saunders A. D., White R. V., Al'mukhamedov A. I., Medvedev A. Ya. Geochemistry and petrogenesis of basalts from the West Siberian Basin: an extension of the Permo-Triassic Siberian Traps, Russia // Lithos. 2005. Vol. 79. P. 425–452. <https://doi.org/10.1016/j.lithos.2004.09.011>
19. Goble R. J. Copper sulfides from Alberta: yarrowite Cu_9S_8 and spionkopite $\text{Cu}_{38}\text{S}_{28}$ // Canadian Mineralogist. 1980. Vol. 18. P. 511–518.
20. Спиридонов Э. М., Плетнев П. А., Перельгина Е. В., Рапопорт М. С. Геология и минералогия месторождения медистого золота Золотая Гора (Карабашское), Средний Урал. М.: МГУ, 1997. 192 с.
21. Власов Е. А., Прокофьев В. Ю., Николаев Ю. Н., Калько И. А. Новая находка золото-теллуридной минерализации на Чукотке: минералогия и условия формирования рудопроявления Телевеем // Руды и металлы. 2016. № 4. С. 48–59.
22. Goble R. J., Robinson G. Geerite, $\text{Cu}_{1.60}\text{S}$, a new copper sulfide from DeKalb Township, New York // Canadian Mineralogist. 1980. Vol. 18. P. 519–523.
23. Le Bas M. J., Le Maitre R. W., Streckeisen A., Zanettin B. A chemical classification of volcanic rocks based on the total alkali-silica diagram // Journal of Petrology. 1986. Vol. 27. P. 745–750. <https://doi.org/10.1093/petrology/27.3.745>
24. Sun S. S., McDonough W. F. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes // Magmatism in Ocean Basins. London: Geological Society Special Publications, 1989. P. 313–345. <https://doi.org/10.1144/GSL.SP.1989.042.01.19>
25. Ponomarev V. S., Erokhin Yu. V., Ivanov K. S. Composition of basalts from the pre-Jurassic basement of Western Siberia (West-Tarkosalinskaya area, Yamalo-Nenets autonomous district) // Изв. УГГУ. 2017. Вып. 1 (45). С. 14–18. <https://doi.org/10.21440/2307-2091-2017-1-14-18>
26. Пономарев В. С., Иванов К. С., Ерохин Ю. В. Вещественный состав базальтов и долеритов из доюрского основания Западно-Сибирской плиты (Верхнехудосейская площадь, ЯНАО) // Изв. вузов. Северо-Кавказский регион. Естественные науки. 2019. № 3. С. 62–69.
27. Pearce J. A., Cann J. R. Tectonic setting of basic volcanic rocks determined using trace element analyses // Earth and Planetary Science Letters. 1973. Vol. 19. P. 290–300. [https://doi.org/10.1016/0012-821X\(73\)90129-5](https://doi.org/10.1016/0012-821X(73)90129-5)
28. Winchester J. A., Floyd P. A. Geochemical discrimination of different magma series and their differentiation products using immobile elements // Chemical Geology. 1977. Vol. 20. P. 325–343. [https://doi.org/10.1016/0009-2541\(77\)90057-2](https://doi.org/10.1016/0009-2541(77)90057-2)
29. Pearce J. A., Norry M. J. Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks // Contributions to Mineralogy and Petrology. 1979. Vol. 69. P. 33–47.

Статья поступила в редакцию 30 марта 2020 года