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Mineralogy of schists from the basement of the southwestern part of the Tazovsky peninsula of the West Siberian megabasin (Lenzitskaya oil exploration area, YNAD)

Vladimir Sergeevich PONOMAREV*,
Kirill Svaytoslavich IVANOV**,
Vera Vital'evna KHILLER***

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

Relevance of the work. The crystalline basement of Western Siberia is a promising site in the search for oil and gas, but not a sufficiently studied subject. Promising rocks are granitoids and partly their metamorphic margins. Core samples from wells, which uncovered rocks of the basement of Western Siberia, are unique because they are rare and extremely difficult to access, so it is necessary to conduct a comprehensive detailed core study for geodynamic reconstructions and to consider the geological evolution of the region.
Purpose of the work. The determination of the material composition of quartz-chlorite-mica schists from the pre-Jurassic basement of the northern (Arctic) part of the West Siberian megabasin uncovered by the Lenzitskaya well No 77 (depth is 3516–3502 m) 265 km east of Salekhard within the Yamalo-Nenets Autonomous District (YNAD).
Results. The studied quartz-chlorite-mica schists are fine-grained rocks of a greenish-gray color; they have an interdigitation of thin beds of rock enriched in mica-quartz-carbonate substance (up to 2 mm thick) with a small amount of chlorite, and layers of quartz-chlorite-mica composition (up to 3 mm) with the presence of carbonate boudin. Intimate crumpling is often observed in the rock. In the lower part of the section (depth is 3516 m), the rocks have a medium-grained structure and are composed of calcite (60%), quartz (25%), mica (10%) and chlorite (5%). The quartz-sericitic-chlorite-carbonate rock has a schistous form due to light layers of quartz-calcite composition with a thickness of up to 2 cm and thin layers of a chlorite-mica aggregate with a thickness of up to 2 mm. The following was established using X-ray electron probe microanalyzer CAMECA SX 100: muscovite, aluminoceladonite, quartz, chamosite, calcite, plagioclase, pumpellyite-(Fe^{2+}), rutile, fluorapatite, monazite, zircon, pyrite and chalcopyrite. Quartz-sericitic schists similar in composition were found by us in the basement rocks of the Priuralsky part of the West Siberian plate in the Shaimsk-Kuznetsovsk megaanticlinorium.
Conclusion. The mineralogy of quartz-chlorite-mica schists from the pre-Jurassic basement of the northern part of the West Siberian megabasin (Lenzitskaya 77 well, depth is 3502–3516 m) was first described. It was established that the formation of quartz-chlorite-mica schists took place under the conditions of the upper prehnite-pumpellyite facie of metamorphism along the sedimentary substance. Later the rocks underwent changes in the process of propitilization.

Keywords: quartz-chlorite-mica schists, mineralogy, metamorphism, basement, West Siberian megabasin, YNAD.

Introduction

The study of the geology, tectonics and material composition of the pre-Jurassic basement of the West Siberian megabasin was carried out by many researchers [1–5 and others]. At the same time, studies of the geology of the Arctic and the Arctic part of Western Siberia are of great importance in connection with possible oil-and-gas content of this vast and still insufficiently studied territory and its possible upcoming division between countries. It is known that the most important criterion here is the results of the study of the basement of the sedimentary basins of the Arctic. The Yamal Peninsula and its nearest margins are the main gas provinces of our country and one of places where the crystalline basement is available for direct study (albeit with great difficulty). The basements of oil and gas provinces are still one of few promising, but insufficiently studied objects. Interestingly, the granitoids of basements (in part, their metamorphic margins) are the most promising in the search for oil and gas [6–8 et al]. Core samples from wells, which uncovered rocks of the basement of Western Siberia, are unique because they are rare and extremely difficult to access, so it is necessary to conduct a comprehensive detailed core study for geodynamic reconstructions and to consider the geological evolution of the region. In this paper, the mineralogy of quartz-chlorite-mica schists from the pre-Jurassic basement of the northern (Arctic) part of the West Siberian megabasin (uncovered by the Lenzitskaya No 77 well at a depth of 3516–3502 m) is examined in detail for the first time.

Geological setting of the Lenzitskaya area

The Lenzitskaya oil and gas exploration area (on the territory of which the Lenzitsky oil field was discovered during the drilling of the exploratory well No. 70 in 1985) is located in the south-western part of the Tazovsky peninsula at the southern coast of the Gulf of Ob 265 km east of Salekhard within the Yamalo-Nenets Autonomous District (Fig. 1).

Historical [9], the well of Lenzitskaya No 70 at a depth below 3500 m helped to reveal rocks of the pre-Jurassic basement represented by green schists. The explanatory note to the State Geological Map of the Russian Federation [9] indicates that Upper Proterozoic undivided metamorphic formations are established at the Lenzitskaya area. It is noted that in the Medvezhye oil and gas exploration area located southward, the schists similar in mineral composition were found by wells No 1001 (within the interval of 4458–4605 m), as well as Sosninskaya (well No 16) and Ugutskaya (well No 73) oil and gas exploration areas. The Upper Proterozoic age of metamorphic schists is determined based on their similarity in composition and level of metamorphism with the metamorphites of the lower subsequence of the Sukhopit suite of the Upper Proterozoic of the Yenisei Ridge [10 et al.].

* ✉ p123v@yandex.ru
https://orcid.org/0000-0002-1651-1281
**ivanovks@igg.uran.ru
https://orcid.org/0000-0002-8292-4658
***hilvervit@mail.ru
https://orcid.org/0000-0001-8491-4958

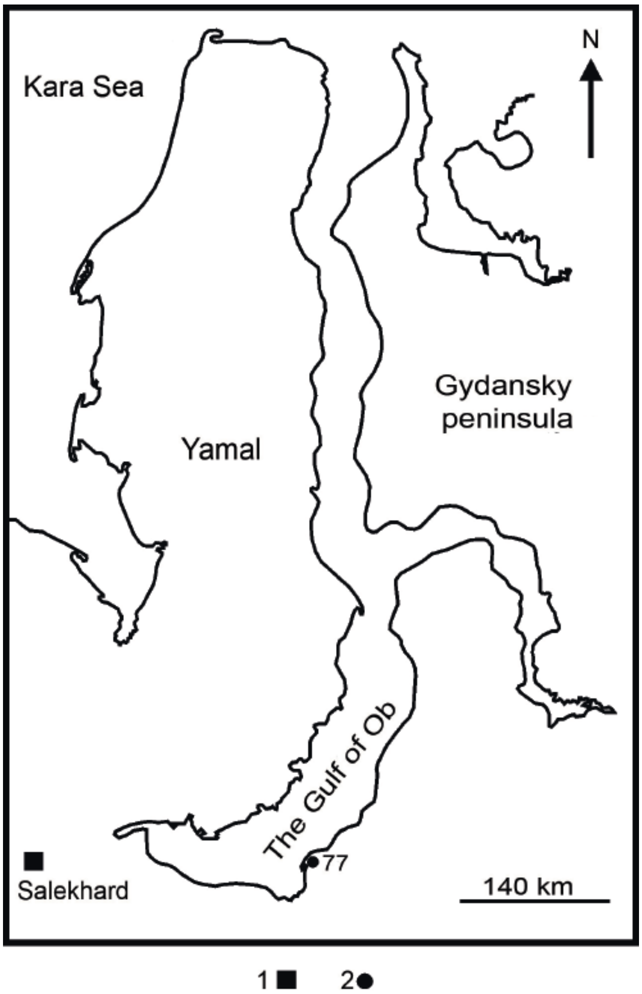

Figure 1. Schematic map of the location of the Lenzitskaya well No 77. 1 – residental area, 2 – well.
Рисунок 1. Схематическая карта расположения скважины Лензитская № 77. 1 – населенный пункт, 2 – скважина.

Research results and their discussion

The studied core is represented by fine-grained, highly deformed quartz-chlorite-sericitic shales (samples from a depth of 3502–3509 m, Fig. 2) and quartz-chlorite-sericitic-carbonate rock (depth of 3515–3516 m, Fig. 3). Microscopically, rocks have a grano-lepidoblast and granoblast structure. The mineral assemblage of the rocks is as follows: muscovite, aluminoceladonite, quartz, chamosite, calcite, plagioclase, pumpellyite. Rutile, fluorapatite, monazite, zircon, pyrite and chalcopyrite are found among accessory and ore minerals.

The rocks are fine-grained, greenish-gray in color; they have an interdigitation of thin beds of rock enriched in mica-quartz-carbonate substance (up to 2 mm thick) with a small amount of chlorite, and layers of quartz-chlorite-mica composition (up to 3 mm) with the presence of carbonate boudin. Intimate crumpling is often observed in the rock. In the lower part of the section (depth is 3516 m), the rocks have a medium-grained structure and are composed of calcite (60%), quartz (25%), mica (10%) and chlorite (5%). The quartz-sericitic-chlorite-carbonate rock has a schistous form due to light layers of quartz-calcite composition with a thickness of up to 2 cm and thin layers of a chlorite-mica aggregate with a thickness of up to 2 mm.

In quartz-chlorite-sericitic schists, quartz is represented by polygonal grains with the inclusion of muscovite and apatite. Some of the grains have an undulatory extinction. Grains size is up to 0.5 mm. Micro-folding is shown in the beds enriched with quartz material (Fig. 4). In the superposed folds of the straticules, grains of quartz, mica and chlorite are perpendicular to stratification in the rock. Quartz contains fine grains of short prismatic apatite and zircon as inclusions.

Mica forms fine-grained banded and crimped aggregates usually deformed and folded; it is often observed together with the laths of chlorite. The size of individuals is up to 0.5 mm. Individuals of accessory minerals such as zircon, monazite, apatite and rutile can be found among the chlorite-mica aggregate. According to the modern classification of micas [11], the obtained compositions correspond to muscovite (Table 1, an. 1, 3, 4) and aluminoceladonite (Table 1, an. 4). The content of SiO_2 in micas varies from 44.97 to 46.86 wt. %, Al_2O_3 from 29.94 to 35.33 wt. %. The content of FeO and MgO in aluminoceladonite is 5.91 and 2.86 wt. % respectively. The content of FeO impurities in muscovite is up to 4.62 wt. % MgO to 2.14 wt. %. In the micas, a constant admixture of Na_2O to 0.94 wt. % and TiO_2 to 0.45 wt. % is observed.

Chlorite in the rock tends to the mica aggregate, where it forms self-contained strips or lenses; the mineral also occurs in the form of elongated curved laths in the interstice of quartz and carbonate. Chlorite flake size does not exceed 0.7 mm. Mineral is pleochroic from yellow-green to bluish-green. In terms of composition, chlorite corresponds to magnesian high-alumina cha-

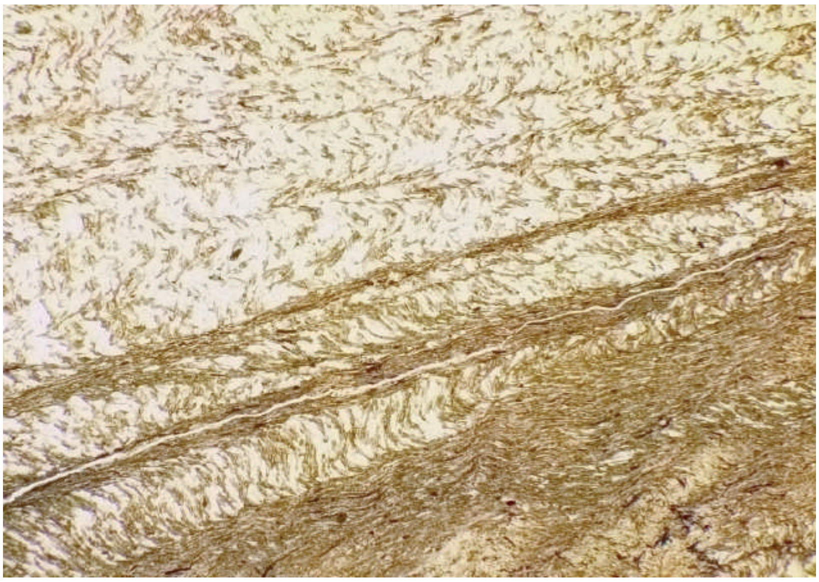

Figure 2. Quartz-chlorite-sericitic schist. The Lenzitskaya well No 77, depth is 3509 m. Incident light. The size of the field of vision is 3 mm.
Рисунок 2. Кварц-хлорит-серицитовый сланец. Скважина Лензитская № 77, глубина 3509 м. Проходящий свет. Размер поля зрения 3 мм.

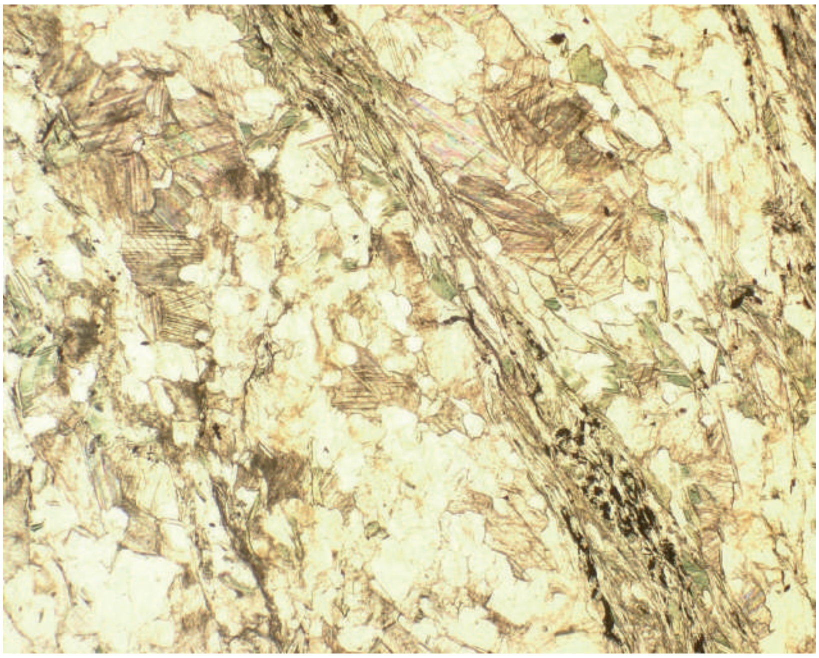

Figure 3. Quartz-chlorite-sericitic-carbonate rock. The Lenzitskaya well No 77, depth is 3516 m. Incident light. The size of the field of vision is 3 mm.
Рисунок 3. Кварц-хлорит-серицит-карбонатная порода. Скважина Лензитская № 77, глубина 3516 м. Проходящий свет. Размер поля зрения 3 мм.

mosite (Table 1, an. 5–8). MgO content in chamosite is up to 13.99 wt. %. One can note MnO up to 0.31 wt. % and Cr_2O_3 to 0.37 wt. % among impurities in the mineral.

The studied rocks contain a large amount of carbonate (5–10%, sometimes up to 60% of the rock volume), which is often confined to areas with fine-grained quartz and forms quartz-carbonate accumulations and veinlets. Carbonate is represented by elongated and isometric, twinned grains up to 1 mm in size. According to microprobe analysis, carbonate corresponds to calcite. Among impurities in the mineral, FeO is noted up to 1.83 wt. %, MnO to 1.22 wt. % and MgO to 0.96 wt. % (Table 1, an. 14–17). There is a small amount of tabular grains of plagioclase with polysynthetic twinning of up to 0.2 mm in size among the quartz-calcite aggregate. By chemical composition, the mineral corresponds to pure albite ($An_{0.2-0.6}$). The content of CaO in albite is up to 0.13 wt. % (Table 1, an. 9–12).

Pumpellyite-(Fe^{2+}) was found by us in thin sections in the form of a fine-grained aggregate of green color in association with calcite and chlorite. It has been established by microprobe analysis that the content of FeO in the mineral reaches 9.71 wt. %. It can be confidently identified as pumpellyite-(Fe^{2+}) by chemical composition with a high content of the pumpellyite-(Al) minal up to 34%. The crystallochemical formula of this pumpellyite is as follows: $Ca_{1.92}(Fe^{2+}_{0.65}Al_{0.34}Mn_{0.02}Ti_{0.01})_{1.02}Al_{2.00}(Si_{1.00}O_4)(Si_{2.06}O_7)$

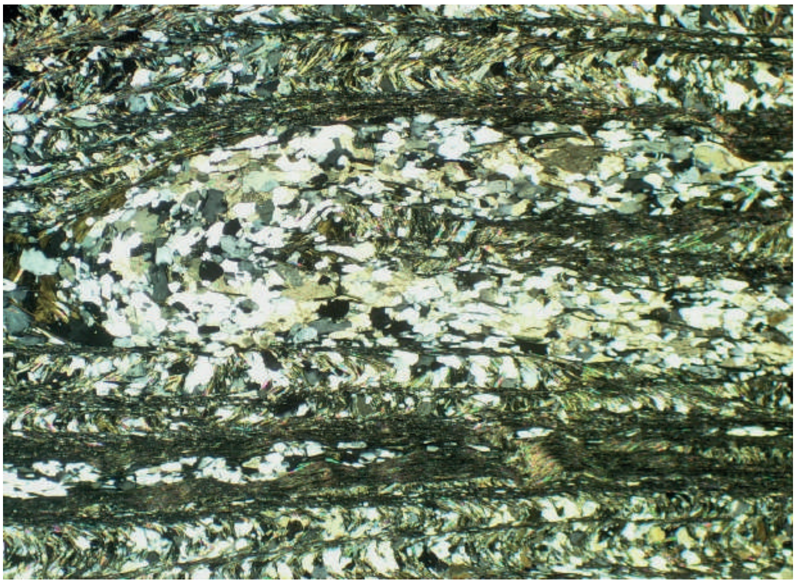

Figure 4. Micro-folding in quartz-chlorite-sericitic schists. The Lenzitskaya well No 77, depth is 3505 m. Polarized light. The size of the field of vision is 3 mm.

Рисунок 4. Микроскладчатость в кварц-хлорит-серицитовых сланцах. Скважина Лензитская № 77, глубина 3505 м. Поляризованный свет. Размер поля зрения 3 мм.

Table 1. Chemical composition of minerals from metamorphic schists, wt.%.

Таблица 1. Химический состав минералов из метаморфических сланцев, мас.%.

Analysis No	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	F	Total
						Muscovite						
1	46.86	0.45	32.41	0.04	2.51	0.04	1.25	0.03	0.94	9.73	0.21	94.47
2	44.97	0.28	32.92	0.07	4.62	0.01	2.14	–	0.80	8.68	0.18	94.67
3	46.42	0.28	35.33	0.05	2.42	0.07	0.57	0.02	0.96	9.54	0.13	95.79
						Aluminoceladonite						
4	46.19	0.22	29.94	0.08	5.91	0.01	2.86	0.02	0.73	8.29	0.20	94.45
						Chamosite						
5	25.04	0.12	21.88	0.17	26.85	0.21	13.37	0.01	0.02	0.01	0.17	87.85
6	25.02	0.14	22.06	0.07	26.84	0.31	13.39	–	0.03	–	0.18	88.04
7	25.17	0.07	21.86	0.05	26.30	0.14	13.99	0.01	–	0.01	0.16	87.76
8	24.73	0.13	22.60	0.37	26.50	0.27	13.20	0.04	–	0.02	0.15	88.01
						Albite						
9	68.21	–	19.32	–	0.40	0.02	0.01	0.13	11.77	0.02	–	99.88
10	67.83	–	18.94	–	0.22	–	0.01	0.07	12.08	0.03	–	99.18
11	68.58	–	19.32	–	0.51	–	–	0.07	12.11	0.01	–	100.60
12	68.32	0.06	19.27	–	0.42	–	–	0.05	12.38	0.04	–	100.54
						Pumpellyite-(Fe^{2+})						
13	38.10	0.08	24.74	0.04	9.71	0.23	0.01	22.37	0.00	0.01	0.06	95.35
						Calcite						
14	–	–	–	–	1.73	0.86	0.83	52.33	–	–	–	55.75
15	–	–	–	–	1.82	0.73	0.73	51.81	–	–	–	55.09
16	–	–	–	–	1.77	1.22	0.84	51.33	–	–	–	55.16
17	–	–	–	–	1.83	0.97	0.96	51.91	–	–	–	55.67

Note: here and in tab. 2 analyzes were performed in the laboratory of the Zavaritsky Institute of Geology and Geochemistry of the Ural Branch (UB) of the Russian Academy of Sciences (RAS) using the CAMECA SX 100 microanalyzer.

$(OH)_2 \cdot H_2O$ (when converted to cationic method). The increased content of Al_2O_3 (24.74 wt.%) is observed in the mineral; the content of FeO is slightly underestimated and there are almost no impurities (Table 1, an. 13). The presence of pumpellyite-(Fe^{2+}) may indicate that the rocks were formed under conditions of prehnite-pumpellyite facie of metamorphism.

Rutile in the rock is the main accessory mineral; it is found both in the form of single individuals up to 0.5 mm in size and in clusters in the chlorite-mica aggregate. Almost all mineral individuals are oriented along schistosity. In thin sections, the mineral forms prismatic and acicular translucent grains of brown color with high relief. The content of TiO_2 in rutile varies from 98.54 to 99.91 wt. %. The composition of the mineral has an admixture of Fe_2O_3 to 0.98 wt. %.

Apatite can be found in the interstice of quartz grains forming isometric and short prismatic grains, the maximum size of which does not exceed 70 μm by elongation. Moreover, the mineral is found in the form of clusters of grains of irregular shape in calcite. The chemical composition of phosphate corresponds to fluorapatite. There are FeO up to 0.33 wt. % and SiO_2 up to 0.40 wt. % among the impurities in the mineral. The fluorine content in the apatite is up to 4.21 wt. %; chlorine is not found.

Monazite in the rock is represented by single grains of irregular shape in the chlorite-mica aggregate. Grain size is up to 20 microns by elongation. According to microprobe analysis, the mineral corresponds to monazite-(Ce) with a Ce_2O_3 content of 27.0 wt. % and La_2O_3 11.9 wt. %. Zircon forms widely-spaced and small short prismatic grains up to 30 microns in size by elongation.

Sulfide mineralization of the studied rocks is represented by pyrite and chalcopyrite. The dominant among the rocks is pyrite. The mineral forms widely-spaced isometric grains and chains located along the schistosity of the rock (Fig. 5). The size of the individuals of pyrite does not exceed 250 microns. The chemical composition of the mineral contains Co impurities up to 0.79 wt. % and Pb up to 0.29 wt. % (Table 2, an. 1-4).

Chalcopyrite occurs in the form of small elongated, irregularly shaped grains up to 40 microns in size in the interstice of pyrite. A small amount of Pb impurity is present in chalcopyrite (up to 0.18 wt.%, Table 2, an. 5–8).

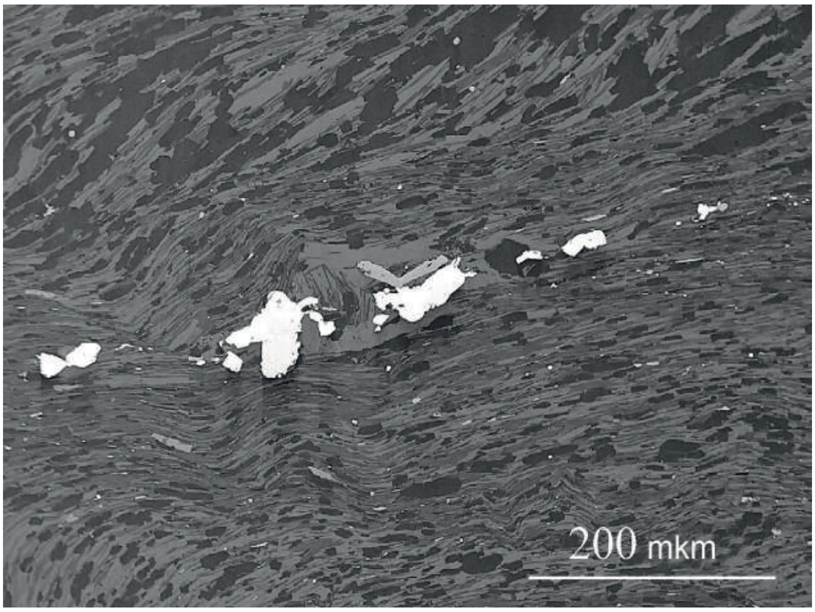

Figure 5. A chain of pyrite individuals (white) in quartz-chlorite-sericitic schist. The Lenzitskaya well No 77, depth is 3509 m. BSE-image, CAMECA SX 100.

Рисунок 5. Цепочка индивидов пирита (белое) в кварц-хлорит-серицитовом сланце. Скважина Лензитская № 77, глубина 3509 м. BSE-изображение, CAMECA SX 100.

Table 2. The chemical composition of sulfides from metamorphic schists, wt. %.

Таблица 2. Химический состав сульфидов из метаморфических сланцев, мас. %.

Analysis No	Fe	Ni	Co	Zn	Cu	Pb	Cd	S	Total
				Pyrite					
1	46.45	0.03	0.20	0.02	0.01	0.06	–	53.52	100.29
2	46.54	0.01	0.02	–	0.01	0.24	–	53.12	99.94
3	46.12	–	0.66	0.07	–	0.29	–	53.80	100.94
4	45.80	0.02	0.79	0.02	0.02	–	–	53.69	100.34
				Chalcopyrite					
5	30.00	–	–	–	34.83	0.18	0.07	34.69	99.77
6	30.15	0.02	–	–	34.62	0.05	0.03	34.52	99.39
7	29.41	0.02	–	–	34.28	0.08	–	34.46	98.25
8	30.55	–	–	–	34.81	0.08	–	35.42	100.86

The temperature of rock formation in the range of 350–360 ˚C is calculated using a chlorite thermometer [12]. The obtained estimated data are close to the upper boundary of the prehnite-pumpellyite facie of metamorphism.

The mineralogy of metamorphic schists from the Lenzitskaya well No 77 differs from the previously studied quartz-plagioclase-mica-chlorite schists from the pre-Jurassic basement of the southern part of Yamal (the West-Yarotinskaya well No 300) by the presence of chamosite, calcite, pumpellyite-(Fe^{2+}), chalcopyrite and monazite. At the same time aluminous chlorite (donbassite), goyazite, dolomite, sphalerite, galena, cobaltite, native copper and silver were found in the schists from the Zapadno-Yarotinskaya well No. 300 [13]. Sulphide mineralization, as well as a large amount of calcite and rutile in quartz-carbonate-chlorite-mica schists, could have formed after the rocks were worked out by late low-temperature solutions with propylitic alteration along cracks at the boundary of two media, metamorphic rocks of the basement and the superincumbent Jurassic-Cenozoic sedimentary strata [14]. Such metamorphic schists are established in the basement of the Priuralsky part of the West Siberian plate, where they have margins for granite massifs and make up the major Shaimsk-Kuznetsovsk megaanticlinorium [15–17].

Conclusions

Thus, we first described in detail the mineralogy of quartz-chlorite-mica schists from the pre-Jurassic basement of the northern part of the West Siberian megabasin (Lenzitskaya well No 77, depth is 3502-3516 m). The mineral assemblage of rocks is represented by muscovite, aluminoceladonite, quartz, chamosite, calcite, albite, pumpellyite-(Fe^{2+}), rutile, fluorapatite, monazite-(Ce), zircon, pyrite and chalcopyrite. Quartz-sericitic schists similar in composition were found by us in the basement rocks of the Priuralsky part of the West Siberian plate in the Shaimsk-Kuznetsovsk megaanticlinorium. The formation of rocks occurred under the conditions of the upper prehnite-pumpellyite facie of metamorphism along the sedimentary substance. Later the rocks underwent changes in the process of propitilization.

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Минералогия сланцев из фундамента юго-западной части Тазовского полуострова Западно-Сибирского мегабассейна (Лензитская нефтеразведочная площадь, ЯНАО)

Владимир Сергеевич ПОНОМАРЕВ*,
Кирилл Святославич ИВАНОВ,**
Вера Витальевна ХИЛЛЕР***

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

Актуальность работы. Кристаллический фундамент Западной Сибири является перспективным на поиски нефти и газа, но недостаточно изученным объектом. Перспективными породами являются гранитоиды и отчасти их метаморфическое обрамление. Образцы керна из скважин, вскрывших породы фундамента Западной Сибири, являются уникальными, так как являются редкими и крайне труднодоступными, поэтому необходимо проводить всестороннее детальное исследование керна для геодинамических реконструкций и рассмотрения геологической эволюции региона.
Цель работы. Определение вещественного состава кварц-хлорит-слюдистых сланцев из доюрского фундамента северной (арктической) части Западно-Сибирского мегабассейна, вскрытых скважиной Лензитская № 77 на глубине 3516–3502 м, которая расположена в юго-западной части Тазовского полуострова на южном побережье Обской губы, в 265 км к востоку от г. Салехард в пределах Ямало-Ненецкого автономного округа.
Результаты. Исследуемые кварц-хлорит-слюдистые сланцы – тонкозернистые породы зеленовато-серого цвета, в которых наблюдается чередование слойков, обогащенных слюдисто-кварц-карбонатным веществом (мощностью до 2 мм) с небольшим количеством хлорита, и слоев кварц-хлорит-слюдистого состава (мощностью до 3 мм) с наличием будин карбоната. Часто в породе наблюдается микроскладчатость. В нижней части разреза (глубина 3516 м) породы имеют среднезернистую структуру и сложены на 60 % кальцитом, 25 % кварцем, 10 % слюдой и 5 % хлоритом. Кварц-хлорит-серицит-карбонатная порода имеет сланцеватый облик за счет светлых слоев кварц-кальцитового состава мощностью до 2 см и тонких слоев хлорит-слюдистого агрегата мощностью до 2 мм. С помощью рентгеноспектрального электронно-зондового микроанализатора CAMECA SX 100 в породах установлены: мусковит, алюминоселадонит, кварц, шамозит, кальцит, плагиоклаз, пумпеллиит-(Fe^{2+}), рутил, фторапатит, монацит, циркон, пирит и халькопирит. Близкие по составу кварц-серицитовые сланцы встречены нами среди пород фундамента Приуральской части Западно-Сибирской плиты в Шаимско-Кузнецовском мегантиклинории.
Вывод. Впервые описана минералогия кварц-хлорит-слюдистых сланцев из доюрского основания северной части Западно-Сибирского мегабассейна (скв. Лензитская 77, гл. 3502–3516 м). Установлено, что образование кварц-хлорит-слюдистых сланцев происходило в условиях верхов пренит-пумпеллиитовой фации метаморфизма по осадочному субстрату, позже породы подверглись изменению в процессе пропилитизации.

Ключевые слова: кварц-хлорит-слюдистые сланцы, минералогия, метаморфизм, фундамент, Западно-Сибирский мегабассейн, ЯНАО.

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* ✉ p123v@yandex.ru
https://orcid.org/0000-0002-1651-1281
**ivanovks@igg.uran.ru
https://orcid.org/0000-0002-8292-4658
***hilvervit@mail.ru
https://orcid.org/0000-0001-8491-4958

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