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Sodium Geochemistry in Terrigenous Complexes in Connection with Problem of Gold Content

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***Abstract*—Barth's concept about sodium ingress into metamorphic rocks directly from the buried seawater sediments is considered in the paper. This concept solves the problem of sodium balance according to the Vernadskiy studies of geochemical cycles. Basing on this concept, sodium geochemistry in auriferous terrigenous complexes in different regions of Russia and other CIS countries is analyzed. It has been demonstrated that the sodium enrichment in terrigenous rocks occurs not only during the metamorphism process but also in formation of sedimentary rocks under the conditions of avalanche sedimentation and fast sediments immersion in the zone of catagenesis. The sodium is fixed in albite under thermodynamic conditions of catagenesis. Chloride is not finding its own mineral phase and transports gold from the mineral phase to the exfiltration silicate waters, because it has the high activity with respect to gold. Metallogenic result of this process is the formation of auriferous quartz veins and stringer zones in drain sandstone beds. Metallogenic specialization of normal potassic terrigenous sequences is determined by different factors displayed during the processes of sediment genesis and diagenesis or the future processes of metamorphism and (or) intrusive magmatism.**

Keywords*—*Barth's concept; sodium ingress; geochemical cycles; fast sediments immersion; mineral phase; intrusive magmatism

I. INTRODUCTION

The largest golden-ore deposits of Russia and other countries of the world are located in the black-shists strata, often disjointedly with magmatism occurrences. Many of them occur in rocks being not subject even to green-slate metamorphism. The two circumstances themselves are dictating the necessity to view the formation of such deposits together with the history of the formation of ore containing series. At present time the models of similar deposits on the base of notions about the syngenesis of the ore- and ore-containing formations are being developed [1]. At the same time, the substantial role is attributed to the study of rare and scattered elements and organic matter [2]. The study of rock-forming chemical elements plays a far lesser role. At the same time, just the geochemistry of rock-forming chemical elements reflects most objectively peculiarities of lithogenesis, providing physical-chemical and thermodynamic conditions for re-distribution and concentration of matter in anisotropic laminated series, necessary for the realization of ore formation processes. The alkaline rock-forming elements and in particular sodium are the most significant in this relation.

II. Methodology and Research Methods

The methodological basis of the study is Barth's concept of considered sodium ingress into metamorphic rocks from the buried seawater sediments. Basing on this concept, sodium geochemistry in auriferous terrigenous complexes in different regions of Russia and other countries is analyzed.

According to the teaching of V.I. Vernadskiy about geochemical cycles, all chemical elements in the Earth's crust "make reversible closed cycles, always renewed and identical" [3]. The weathering products of continental rocks accomplish the circulation through marine environment, accumulating in deep-sea trenches, returning to the continents in the form of sedimentary and derivative from metamorphic and magmatic rocks. Therefore, the average chemical composition of the rocks of continents must correspond to the average composition of sedimentary rocks. However, for sodium, such correspondence is not found. The fact of relatively low content of sodium in sedimentary rocks motivated V.M. Goldsmith to suppose the existence of incomplete geochemical cycles [4], which contradicted to the teaching of V.I. Vernadskiy. Later on, T. Barth demonstrated that "notorious deficit of sodium in sedimentary rocks is not an obstacle for constructing the model of endless geochemical cycles" [4]. According to his concept, sodium comes into metamorphic rocks immediately from buried in the geosyncline sediments porous waters during their metamorphism at great depth in the Earth's crust. But if the sediments had experienced uplift above the sea level even before they were subject to metamorphism, then the sodium contained in the pores was leached out and entered the sea again. Therefore, according to the opinion of T. Barth, results of chemical analyses of such rocks cannot be taken into account in connection with the geochemical balance of sodium. This is in accordance with the calculations [5], based on the possibility of constructing the balance of sodium with the calculation of its mass in the ocean. Indeed, if we compare chemical composition of the contemporary deep-sea sediments with the preserved pore solution [6] and without it [7], then in the first case the content of Na_2O (3.17 %) corresponds to the average composition of the rocks of continents and in the second one (1.27 %) – to the average composition of sedimentary rocks. One would think that the question is solved. However, statistical study of Na_2O distribution in the metamorphic schists of the Earth globe [8] has shown two levels of its content values. The first (2.5-3.5 %) does not find analogs among sedimentary formations and is characteristic only for metamorphic rocks, what corresponds to the concept of T. Barth, the second (0.6-1.6 %) is usual for unmetamorphosed sedimentary rocks, what contradicts to this concept. Thus, the metamorphic shcists are formed both out of fresh water-containing sediments, and out of sedimentary rocks that have lost the pore sodium. Besides that, in the course of regional geochemical investigations [9, 10] there were revealed terrigenous complexes that have not experienced even greenshist metamorphism but having a high content of Na_2O. Therefore, enrichment of terrigenous series in sodium can take place without rock metamorphism, even on the stage of lithogenesis.

III. Results and Discussions

The Upper Proterozoic deposits of the periphery of the Rostov bulge of the Ukrainian shield are highly significant in this relation. They are united in the composition of the Syniavian series and contain ore manifestations of copper and gold [11]. For the first time we have attracted attention to the peculiarities of the structure of the Syniavian series, composition of rocks forming it, and golden mineralization manifested in them in connection with the geochemistry of sodium and appearing by this minerogenetic specialization [12].

The Syniavian series lies over metamorphic rocks of Lower Proterozoic with a regional disconformity and is composed entirely of sedimentary formations. By peculiarities of its structure and lithological composition, it is clearly divided into two parts. Different sandstones with sparse interlayers of aleurolites, sericite-chlorite and phyllite-like shists, dolomites and volcanics prevail in the lower one (total thickness of about 2000 m). The upper part (thickness not less than 600 m) is almost completely composed of conglomerates, Chaltyrian, Khavalyshian and Chadrynian suites are distinguished (from the bottom to the top) in the composition of lower part of the Syniavian series according to the prevalence of such or other varieties of rocks and character of interleaving. Thick layers of dolomites are embedded in upper parts of the Khavalyshian and Chadrynian suites. The upper part of the series (the Temernitskaya suite) almost completely consists of conglomerates with sparse interlayers of sandstones. It lies with erosion on the top of deposits of lower part of the Syniavian series and on the Lower-Proterozoic rocks.

Sandstones, prevailing in Chaltyrian and Khavalyshian suites, are the most widespread rocks of the Syniavian series. Sandstones are found in the form of separate interlayers in the Temernitskaya suite. Further, by their spreading, conglomerates follow making almost completely the Temernitskaya suite and being met in the shape of separate layers in the Chaltyrian suite. Post-sedimentation transformations of terrigenous rocks correspond to the cata- and metagenesis. They are manifested in schistose structures, recrystallization of cement into the quartz-albite-hydromicaceous aggregate, appearance of porphyroblastic, and for a low content of cement in sandstones – granoblastic structures. Moreover, albitization and chloritization of basic tissue of pebbles of effusive rocks, chloritization of dark-coloured minerals and albitization of feldspars of intrusive rock fragments are developed in conglomerates.

The chemical composition of ore-bearing sandstones even in the limits of one suite varies significantly in connection with variations of initial conditions of accumulation of the sediments, revealed by geological data [13]. However, independently of this fact, a clear regularity is outlined in the distribution of contents of petrogenic alkaline elements: in the sandstones of lower part of the Syniavian series (Chaltyrian, Khavalynian and Chadrynian suites) K_2O is dominating over Na_2O, while in the sandstones of the Temernitskaya suite a reverse correlation is observed (Table I).

In the cement of conglomerates of this suite, also being subject to significant variations of mineral and chemical composition, the significant prevalence of Na_2O over K_2O is also fixed. It is especially significant that sandstones, making lower suites of the Syniavian series and characterized in native occurrence by a prevalence of K_2O over Na_2O, in the composition of pebbles of conglomerates of the Temernitskaya suite, acquires a principally different correlation of these oxides (in favor of Na_2O). An attention is drawn also to a high content of Na_2O by relatively low K_2O in pebbles of the most different magmatic rocks from the Temernitski conglomerates. All this testifies the epigenetic nature of sodium specialization of the Temernitskaya suite rocks.

In this way, the causes of differences in alkalinity of terrigenous rocks of lower and upper parts of the Syniavian series are explained by the stated above concept of T. Barth and confirmed clearly by the data adduced. Proceeding from this concept, the regional albitization of rocks of the Temernitskaya suite is connected with activation of buried in pores of the sediment in conditions of catagenesis chloride-sodium marine waters.

Our investigation (carried out in connection with the minerageny of gold) of the chemical composition of ore-bearing terrigenous, including metamorphized, complexes of different gold-bearing provinces of Russia and CIS allowed us to reveal two types of them [14, 15]. The first type is represented by mainly initially pelitic rocks with normal for sedimentary formations values of K_2O and Na_2O content, analogous by chemical composition to clays and clayey shales of the geosynclines, by [16]. The second type is represented by strata of interbedding various, primarily pelitic, aleuritic and psammitic rocks, a common peculiarity of which is anomalously high for terrigenous sedimentary formations content of Na_2O with normal K_2O. It is necessary to emphasize that potassium or sodium specialization of terrigenous strata is stated not only in limits of the deposit but also remains along the strike of strata, i.e. the anomalous sodium specialization is not acquired as a result of possible ore-accompanying metasomatic processes but is a property of the rocks themselves, independently of the fact whether they have mineralization or not.

Owing to considrable diversity of geological conditions of localization, different researchers, independently from one another, unite all golden-ore deposits in terrigenous complexes into two groups, called in the literature as golden-ore formations [17], mineral-morphologic types [14, 15], ore-formational groups [18] and geological-genetic types [19]. The main criterion by that is the substantial composition of ores and, as a result, the morphology of ore bodies. To the first group, all researchers attribute deposits of impregnated, veinlet-impregnated golden-sulfide ores, to the second – vein and vein-streaky golden-quartz ores.

Ore bodies of the first group deposits are represented by the stratiform seam-like, saddle- lens-, band-shaped ledges (deposits Sukhoi Log, Olimpiadinskoye, Daugyz et al) and oblique-intersecting sulfide-impregnated zones with signs of repeated crushing (deposits Mayskoye, Malomyr et al).

TABLE I. CHEMICAL COMPOSITION (REDUCED TO 100%) AND RELATION Na_2O/K_2O INDIFFERENT ROCKS OF THE SINYAVSKAYA SERIES (THE ROSTOV BULGE OF THE UKRAINIAN SHIELD)

Number of analysis	Average grade, %											
	SiO_2	*TiO_2*	*Al_2O_3*	*Fe_2O_3*	*FeO*	*MnO*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*P_2O_5*	*Na_2O/K_2O*
1	82.4	0.12	7.76	1.91	0.58	0.02	1.28	0.78	1.76	2.91	0.08	0.6
2	76.32	0.42	12.14	2.44	0.86	0.07	2.34	0.88	1.98	2.4	0.15	0.82
3	92.88	0.12	2.43	1.21	0.14	0.02	1	1.06	0.5	0.6	0.04	0.83
4	85.4	0.19	5.29	0.58	1.73	0.04	1.42	2.53	0.85	1.93	0.04	0.44
5	71.56	0.49	12.4	1.5	2.09	0.02	2.3	2.95	2.84	3.8	0.05	0.75
6	77.7	0.17	9.06	2.06	0.58	0.06	2	3.54	1.83	2.94	0.06	0.62
7	67.38	0.56	15.67	1.8	3.31	0.03	3.2	1.79	4.56	1.5	0.2	3.04
8	76.04	0.12	12.2	1.02	2.02	0.06	0.4	1.67	5.76	0.65	0.06	8.86
9	65.92	0.58	13.47	2.4	3.96	0.1	5.25	4.77	2.26	1.2	0.09	1.88
10	75.86	0.36	11.95	1.66	1.58	0.02	0.32	2.11	5.9	0.23	0.01	25.65
11	69.01	0.43	11.55	1.68	3.16	0.06	2.78	7.11	3.04	1	0.18	3.04
12	65.2	0.74	12.58	1.66	4.34	0.03	4.25	6.97	3.48	0.49	0.26	7.1
13	77.12	0.2	12.52	1.36	0.93	0.74	1.28	1	4	0.74	0.11	5.4
14	73.35	0.38	11.65	2.26	2.66	0.06	1.94	2.56	4.77	0.29	0.08	16.45
15	67.3	0.66	13.33	3.36	2.3	0.1	1.86	6.57	4.1	0.3	0.12	13.67
16	62.6	0.56	16.08	2.98	2.67	0.07	2.67	5.12	4.89	2	0.36	2.45
17	57.3	1.14	16.9	2.38	8.19	0.03	7.98	2.02	3.48	0.1	0.28	34.8
18	77.44	0.1	12.76	1.95	0.86	0.02	0.72	1.1	4.8	0.14	0.11	34.29
19	75.84	0.16	12.12	1.48	2.3	0.04	0.41	1.89	5.2	0.54	0.02	9.63
20	68.76	0.51	15.6	1.16	1.08	0.33	2.08	3.24	6.39	0.52	0.33	12.29
21	73.7	0.24	13.71	1.82	1.83	0.04	1.53	2.23	3.64	1.24	0.02	2.94
22	59.7	0.98	18.64	3.22	2.94	0.06	3.36	4.26	3.6	3	0.24	1.2
23	64.6	1.02	16.27	3.21	2.59	0.06	1.7	2.98	5.92	1.48	0.17	4
24	63.1	0.67	16.86	3.69	2.81	0.06	2.19	4.02	6.06	0.49	0.14	12.37

Note. 1-8 – sandstones of the suites (1,2 – chaltyrskaya; 3,4 – khavalyshskaya; 7,8 – temernitskaya); 9,10 – cement of conglomerates, temernitskaya suite; 11-24 – rocks from the pebbles of conglomerates, temernitskaya suite (11,12 – metasandstones, 13 – liparite, 14 – liparite-dacite, 15 – andesite, 16 – trachyandesite, 17 – basalt, 18 – granophyre, 19 – granite-porphyre, 20 – plagiogranite-porphyre, 21 – plagiogranite, 22 – diorite, 23 – quartzose diorite, 24 – granodiorite).

The content of sulfides in either ore bodies varies from 3 to 8 %. They are represented by various combinations of pyrite, arsenopyrite and pyrrhotite. Mainly pyritic (deposits Sukhoi Log and Malomyr), arsenopyrite (Verninskoye and Voroshilovskoye), pyritic- arsenopyrite (Daugyz and Mayskoye), and pyrrhotite -pyritic- arsenopyrite (Olimpiadinskoye and Veduga) ores are distinguished. Fine native gold is closely linked with sulphides. At some deposits (Sukhoi Log, Daugyz, Mayskoye, Voroshilovskoye) there are noted later relatively to the sulfide zones quartz veins.

Ore bodies of the deposits of the second group are represented by separate stratiform seam-like and saddle-shaped, and also intersecting quartz veins (deposits Duet, Yur, Kular, Yemelyanovskoye, Sovinoye, Tokur et al) and vein-streak (stockwork) zones of various morphology (deposits Muruntau, Nezhdaninskoye, Sovetskoye, Natalkinskoye et al). The veins and streaks are more than by 90 % built of quartz. Of other vein minerals, there are noted everywhere albite and carbonates.

The minerals specific for separate deposits are potassium feldspar, garnet, biotite, sericite, chlorite. The content of sulfides in the quartz veins and streaks is from 1-2 % to 5 %. They are represented everywhere by pyrite and arsenopyrite in various correlations. In strictly subordinate quantity there are revealed sulfides of late generations (sphalerite, chalcopyrite, pyrrhotite, marcasite et al). Rather large particles of native gold are placed in the quartz.

It turned out to be that the deposits of the first group are localized in the terrigenous strata with normal potassium specialization, deposits of the second group (including the deposit Muruntau [20]) – in the terrigenous strata with anomalous sodium specialization (Table II). In the limits of ore fields, ore areas, and even minerogenic provinces, as a rule, one of the mentioned mineral types of golden-ore deposits is developed in conformity with the type of alkalinity of ore-bearing terrigenous complexes. So, for example, in the Verkhoyano-Kolymskaya region practically at all its extent all golden-ore deposits are represented only by the quartz-vein type in conformity with regionally displayed sodium specialization of ore-containing Verkhoyanski terrigenous complex. In the most studied Yano-Kolymskaya province, all known 54 deposits and more than 400-ore manifestations belong to low-sulfide gold-quartz formation [21]. In the Lenskaya province industrial golden-ore deposits are localized in the phyllite-like shists of the Khomolkhinskaya suite of upper Riphean with normal potassium type of alkalinity and are represented by sulfide-impregnated type (Sukhoy log, Verninskoye et al). Gold-bearing quartz veins are sometimes noted in limits of this province, but they are formed later than sulfide-impregnated ores [22]. In the North-Yenisey province deposits of a sulfide-impregnated type also have prevailing development (Olimpiadinskoye, Veduga et al), localized in the potassium parashists of the Udereiskaya suite of lower Riphean. Existing in this province deposits the quartz-vein type (Sovetskoye, Eldorado et al) separate themselves off into individual ore area. In the Kyzyl-Kum province, the deposits of the quartz-vein and sulfide-impregnated types are, in the main, spatially separated in connection with the type of alkalinity of ore-bearing terrigenous strata. The similar situation is observed in Chukotka [23] and in the Amur-Okhotskaya folded region [24].

All mentioned deposits, independently of the mineral-morphological type, are localized in terrigenous rocks, a common peculiarity of which is a constant admixture of scattered organic matter. Values of C_{org} content in different areas differ substantially. The highest values of C_{org} content (up to 6%) are fixed in the phyllites of the Khomolkhinskaya suite of upper Riphean containing the deposit Sukhoi Log, the smallest (0.2-0.5 %) – in the phyllites of the Udereiskaya suite of lower Riphean, containing the deposit Sovetskoye. In other areas the content of C_{org} usually does not exceed 1 %.

As a tendency, it can be noted that terrigenous complexes containing deposits of sulfide-impregnated type are usually more enriched by scattered organic matter than terrigenous complexes containing deposits of the quartz-vein type.

The degree of metamorphism of ore-containing rocks is also different, sometimes even in the limits of one ore field. The highest degree of metamorphism is characteristic for the North-Yenisey province. In the area of quartz-vein deposit Eldorado it is epidote-amphibolite and amphibolite facies [25], in sulfide-impregnated Olimpiadinskoye – epidote-amphibolite, and in Veduga and in the area of Sovetskoye deposit – green-slate facies. In the Lenskaya province, all ore-containing rocks belong to different subfacies of the green-slate facies of metamorphism [22]. In the Verkhoyano-Kolymski belt and at Chukotka the rocks of the ore-containing Verkhoyanski complex are not metamorphized at all [23]. The transformations of these rocks relate to the latest stages of lithogenesis – cata- and metagenesis and do not reach conditions of the green-slate facies of metamorphism [26]. In the Amur-Okhotsk region, golden-ore deposits are placed in terrigenous rocks of different degree of metamorphism (from green-slate to epidote-amphibolite) and in unmetamorphosed series.

In this way, the single objectively stated difference between terrigenous complexes with a different mineral-morphological type of golden mineralization is a different level of Na_2O content in them (Table II). In terrigenous complexes with normal (potassium) type of alkalinity, deposits of the sulfide-impregnated ores prevail. Quartz veins and streaks are found in them, but they are found later than sulfide ores, and, as a rule, are not gold-bearing. In terrigenous complexes with anomalous (sodium) type of alkalinity, there are developed only deposits of the golden-quartz vein- and vein-streak type. The industrial golden ore deposits of the sulfide-impregnated type in the sodium terrigenous series have not been revealed until now.

From all mentioned above, it follows that formation of deposits of the golden-quartz type is closely connected with the geochemistry of sodium. Such connection is observed most distinctly in the Verkhoyano-Kolymski folded belt where all golden-ore deposits are localized in the rocks of Verkhoyanski terrigenous complex of late Paleozoic – early Mesozoic age.

TABLE II. THE AVERAGE CHEMICAL COMPOSITION (TRANSFORMED TO 100%) OF TERRIGENOUS ROCKS WITH GOLD-SULPHIDE (1-10) AND GOLD-QUARTZ (11-24) ORES.

Number of analysis	Amount of samples	Average grade, %											
		SiO_2	*TiO_2*	*Al_2O_3*	*Fe_2O_3*	*FeO*	*MnO*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*P_2O_5*	*Na_2O/K_2O*
1	90	62.56	1.18	17.85	2.02	6.14	0.12	3.42	1.42	1.99	3.17	0.13	0.63
2	80	65.65	1.21	18.49	–	6.51	0.05	2.33	0.42	1.92	3.29	0.13	0.58
3	85	62.93	1.08	19.25	2.75	6.21	0.1	2.02	0.61	1.5	3.4	0.15	0.44
4	72	62.55	1.1	18.41	3.56	6.33	0.12	2	0.92	1.47	3.41	0.13	0.43
5	3	67.64	0.98	17.76	5.34	1.52	0.19	1.48	1.18	0.44	3.26	0.21	0.13
6	3	62.3	1.19	21.48	1.5	6.28	0.09	1.47	0.4	0.67	3.44	0.18	0.19
7	8	64.05	0.72	19.5	5.15	1.18	0.07	1.13	0.44	2.18	5.34	0.24	0.41
8	3	58.85	1.05	20.26	2.59	5.46	0.05	3.97	0.88	1.46	5.18	0.25	0.28
9	3	62.91	0.89	19.32	4.9	3.12	0.05	2.22	0.68	0.78	4.96	0.17	0.16
10	1	62.45	0.9	19.22	1.25	6	0.09	3.33	0.35	1.92	4.27	0.22	0.45
11	10	69.18	0.61	13.73	1.21	3.06	0.03	2.1	1.8	3.82	4.12	0.27	0.93
12	7	65.05	0.8	16.4	2.63	3.83	0.03	2.89	1.1	3.03	4.06	0.18	0.75
13	14	73.85	0.63	12.14	1.03	2.78	0.03	1.93	1.44	3.22	2.76	0.19	1.17
14	8	82.07	0.57	8.12	0.77	1.5	0.04	1.15	1.48	2.62	1.56	0.12	1.68
15	9	77.48	0.69	10.66	0.77	1.74	0.03	1.46	1.03	3.35	2.6	0.19	1.29
16	4	68.69	0.64	16.85	1.13	4.12	0.05	1.52	0.68	2.68	3.41	0.23	0.79
17	11	66.57	0.74	16.02	1.29	4.39	0.05	2.89	1.56	3.14	3.19	0.16	0.98
18	10	73.42	0.53	11.91	0.66	2.38	0.07	1.34	3.45	4.43	1.67	0.14	2.65
19	28	70.03	0.48	14.87	1.05	2.84	0.06	1.47	1.95	3.32	3.78	0.15	0.88
20	4	64.8	0.84	16.66	1.63	3.95	0.06	3.27	1.62	2.87	4.06	0.24	0.71
21	11	67.57	0.73	15.35	1.5	3.61	0.07	1.74	2.01	3.86	3.39	0.17	1.14
22	17	64.33	0.83	17.41	1.41	4.07	0.09	2.99	1.46	2.94	4.26	0.21	0.69
23	2	64.54	0.74	17.57	2.28	4.48	0.08	3.28	0.88	2.88	3.07	0.2	0.94
24	3	70.28	0.58	14.86	1.46	3.69	0.07	2.6	0.63	3.15	2.6	0.12	1.23

Note. 1,2 – carboniferous phyllites, upper-middle Riphean (1 – in the limits of the deposit Sukhoy Log, 2 – beyond its limits); 3,4 – carboniferous phyllites of the sukhopitskaya series, lower Riphean, containing the deposit Olimpiadnenskoye; 5,6 – sandy-slate beds of middle Triassic (the deposit Mayskoye, Chukotka) (5 – ores, 6 – ore-containing carboniferous slates), 7,8 – carboniferous slates of the lower-middle Paleozoic (the deposit Malomyr); 9,10 – carboniferous slates of the lower Paleozoic (the deposit Daugyz, Kyzyl-Kumes) (9 – sulphide-bearing, 10 – without sulphides); 11 – gold-bearing rocks and ores, the deposit Muruntau, by the data of borehole 51; 12 – metapsammites, 13 – metaaleurolites, 14 – meta sandstones of vend-lower Paleozoic (the deposit Muruntau), by the data of borehole MC-2; 15 – ore-containing crystalline chlorite-albite-quartz slates of the ore field Muruntau; 16-18 – ore-containing rocks of the kukkanskaya suite, lower Permian (Yakutia) (16 – aleurolites (the deposit Nezhdaninskoye), 17 – aleurolites and 18 – sandstones (the deposit Duet)); 19,20 – carboniferous sandy-slate beds of middle-upper Paleozoic (the deposit Tokur) (19 – metasandstones and 20 – carboniferous phyllite-like slates in the limits of the ore field); 21 – metasandstones and 22 – ore-containing rocks of Paleozoic age (the deposit Rukosuyevskoye, Sakhalin island) (23 – carboniferous phyllite, 24 – phyllitized sandstones)

The overwhelming majority of gold-bearing quartz veins is placed conformably to bedding or make scalariform veins in the beds of sandstones interbedded among the series of aleuropelitic rocks. An extent of separate conformable veins having usually thickness from 0.2 to 1.0 m reaches 5 km and more. For all that they repeat in detail the folded structure of containing beds. The contacts of veins with containing rocks are not clear; the transition to central part of the veins built of massive milky-white quarts realized through a zone of grey metasomatic quartz. It replaces banded rocks and because of this acquires a striped texture. The veins frequently contain angular inclusions of containing rocks of dimension up to 10 cm and more, representing so-called horizons of inclusion, appearing as a result of invasion into pores of sandy rocks of exfiltration waters from the zones of decompaction and creation of anomalous high bed pressure [27]. The mineral composition of ore bodies is typical for deposits of the low-sulfide formation of golden-quartz type and remains in all deposits of the Verkhoyanski terrigenous complex.

Accumulation of the terrigenous sediments of the Verkhoyanski complex took place at the passive margin of the Syberian platform. It substituted preceding in earlier Paleozoic and late Precambrian carbonate accumulation in connection with change at the end of the Visean stage from arid to a humid climate and global drop of the sea level. According to the carried out investigation [26], sediments of the Verkhoyanski complex represent various avalanche accumulations of grain and suspension autokinetic flows of the valley-fan systems of the continental slope. Taking into account age and facies condition of the sediments, it is possible to suppose that dispersed organic matter in them is represented by particles of superior plants. Vegetable detritus being in a suspended state adsorbed gold from the marine water and was buried in the sediment. The mass, unbalanced by processes of diagenesis organic-mineral, very soon is found in the zone of catagenesis under pressure of overlying sediments. Already at the stage of late catagenesis, in primarily depleted of clayey minerals sandstones, there is noted recrystallization-granulation blastesis at the contacts of sandy quartz grains and plastic deformations in quartz accompanied by silicification and albitization of feldspars. Quartz streaks also appear in the sandstones. In the aleuropelites and clayey sandstones, the catagenesis is revealed in another way, namely in the form of consequent transformation of clayey minerals of the smectite group through mixed-layered phase into the hydromica and partly into chlorite. At the stage of metagenesis, the hydromica 1*Md* is transformed into sericite $2M_1$. All this has an important meaning for the formation of golden mineralization because it leads to irregular heating of the mass of sediments and appearance of migratory forms of silica and gold.

It is known that an irreversible process of compaction of the clayey colloidal-dispersed systems is accompanied by an increase in the temperature of the aggregate. Therefore, in the interbanded sandy-clayey masses must appear temperature gradients caused by the difference of temperature values between the "self-heating" clayey and "cold" sandstone layers. This leads to the intensified exfiltration of waters into the beds of clayless sandstones and forestalling aurigenous mineral genesis in them, which is confirmed by petrographic research [26]. At the depth of 3-5 km in conditions of an avalanche burial of sediments and increased temperature (150-200ºC) the mass albitization of the beds at the expense of sodium of buried in the pores sea waters. The main peculiarity of this geochemical process, determining metallogenic specialization of the beds, is "division" of the geochemistry of sodium and chlorine [28]. Under existing thermodynamic conditions sodium is fixed in the new-formed albite, and chlorine, without forming its own mineral phase, saturates the exfiltration waters and, having a high selective activity to gold, favors its leaching, migration and redistribution in a scale of all rock mass. This takes place in the interval of 150-200 ºC, when, according to the experimental data, a solubility of quartz of sedimentary rocks rises abruptly. In this way, already at the stage of catagenesis there are forming silicic hydrothermal solutions. They are saturated by gold at the expense of its desorption from the particles of carbonaceous matter and solution by free chlorine. The useful load is deposited in the form of conformably to bedding or scalariform veins in relatively "cold" beds of sandstones.

The cited above process was first suggested by us for substantiation of the occurring everywhere gold capacity of terrigenous strata of the Amur-Okhotsk folded region by the data of geochemical study of gold-bearing areas [28]. Later it was confirmed experimentally [29]. In the experiment, the two similar columns of sedimentary rocks were placed in different containers for a long time into equal thermogradient conditions. Water was added into one container and aquatic solution of NaCl – into another. After the end of the experiment in the container with pure water fluid, the initial structure of the rock column was preserved and redistribution of gold not fixed. In the column with NaCl solution very intensive alterations of initial rocks were found: in the lower (high temperature) part an albitization of rocks occurred; in the middle – lots of small cavities strewn with acicular quartz crystals were formed; in the upper (low temperature) part a strong quartzite-like rock penetrated by multitude of acicular quartz crystals, as well as subvertical quartz veinlets, was formed. Simultaneously reduction of gold content in the lower (albitized) part of the column and increase in its middle and upper parts occurred.

The significance of chlorine in the transfer of gold even at low values of temperature is also testified by last data of study of Permian sylvinites of the Upper-Kama deposit at Urals [30], in the undissolved residual of which fine particles (50-80 mkm) of native gold with high assay (981) by its total content in the sylvinite of 0.08-0.48 g/t were established.

IV. Conclusions

1. In this way, the described mechanism of sodium fixation in the terrigenous complexes leads simultaneously to the formation of gold-bearing quartz veins. For all that, beds of aleurolites and argillites act as the generator of gold-bearing silicic solutions which are discharged in the sandstone beds acting as collectors and form leaf-by-leaf and scalariform quartz veins. The degree of their gold capacity is determined by concentration of a noble element in the exfiltration solutions. If gold was absent in the solutions, then barren quartz veins were formed.

2. The terrigenous complexes with potassium specialization developed quite differently. The sediments of such complexes had experienced uplift above the sea level yet before they were subject to catagenesis; that is why sodium contained in pores was leached. Under following metamorphism, such rocks maintained normal for sedimentary rocks potassium type of alkalinity. Minerogenic specialization of potassium strata was determined by quite different mechanisms, manifesting themselves in the course of sedimentation and diagenesis and/or in processes of metamorphism and/or intrusive magmatism.

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