ISSN 1028-334X, Doklady Earth Sciences, 2006, Vol. 408, No. 4, pp. 586–589. © Pleiades Publishing, Inc., 2006.
Original Russian Text © N.M. Chernyshov, S.V. Petrov, 2006, published in Doklady Akademii Nauk, 2006, Vol. 408, No. 2, pp. 234–237.

GEOCHEMISTRY

New Forms of Platinum Group Minerals in Ferruginous Quartzites of the Lebedyan Deposit, Kursk Magnetic Anomaly (Central Russia)

Corresponding Member of the RAS N. M. Chernyshov[a] and S. V. Petrov[b]

Received December 20, 2005

DOI: 10.1134/S1028334X06040179

Two-thirds of the identified reserves and predicted resources of iron ores of Russia are concentrated in five (Mikhailovka, Lebedyan, Stoilo, Stoilo-Lebedyan, and Korobki) deposits of the Kursk Magnetic Anomaly (KMA) [1, 7]. These deposits are developed by three (Mikhailovka, Lebedyan, and Stoilo) ore dressing plants that provide approximately 53% of raw iron ores mined in Russia.

Noble metals are among the most essential and voluminous components extracted from ferruginous quartzites and tailings of ore dressing plants. The noble metals are essential unconventional byproducts of gold–platinum ores in the 21st century [6]. Elucidation of the mode of occurrence of Au and platinum group elements (PGE) plays a crucial role in the choice and development of resource-saving high-tech methods for the comprehensive reworking of strategic metals.

Researchers have scrutinized the mineralogy of gold that makes up economic deposits in several iron ore deposits of the world [2, 4, 7, 8]. Some platinum group minerals (PGM) were first discovered only in ferruginous quartzites of Canada, Brazil, Australia, and Ukraine [2–4, 8]. In Russia, several PGMs (sperrylite, rutheniridosmine, native osmium, platirisdomine, and platosmiridium) were discovered in the Mikhailovka iron ore deposit of the KMA [5, 6].

The subsequent special investigations provided new insights into the mineralogy of PGE and Au in ferruginous quartzites of the KMA. We studied the mode of occurrence of noble metals in compositionally different ferruginous quartzites from the largest iron ore deposit of the KMA (Lebedyan deposit). The productive Korobki Formation (Kursk Group) of the Lebedyan deposit can be divided into two iron ore and two shale subformations. The distribution of noble metals in these subformations is primarily governed by the content of sulfides. Concentrations of the sulfides are maximal at the contact of ferruginous quartzites and intraore carbonaceous shales that serve as the major barrier for the accumulation of sulfur.

In order to elucidate trends of the distribution of noble metals and possible modes of their occurrence,

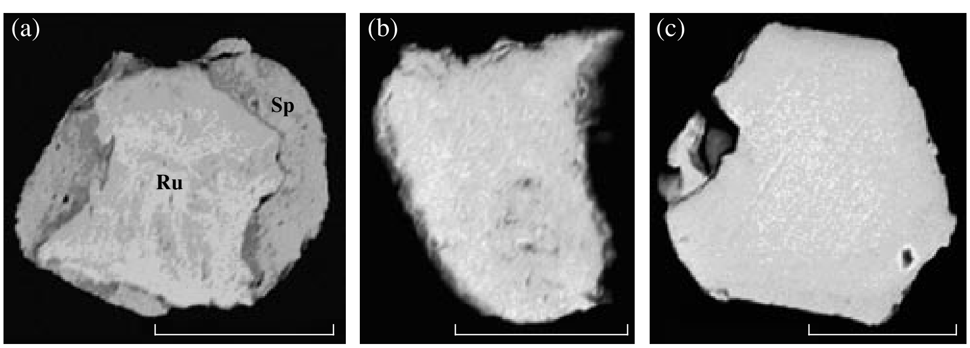

Fig. 1. Modes of occurrence of platinum group minerals in ferruginous quartzites of the Lebedyan deposit. (a) Native ruthenium (Ru) with sperrylite (Sp) rim; (b) native osmium; (c) native ruthenium. Here and in Fig. 2, scale bar is 10 μm.

[a] *Voronezh State University, Universitetskaya pl. 1, Voronezh, 394893 Russia; e-mail: gfkmp107@main.vsu.ru*
[b] *St. Petersburg State University, Universitetskaya nab. 7/9, St. Petersburg, 199164 Russia; e-mail: petrov64@mail.ru*

Table 1. Contents of noble metals (g/t) in sulfidized varieties of ferruginous quartzites of the Lebedyan deposit

Element	A18/2	B18/2	B18/2U	A18/4	B18/4
Ru	0.023	0.032	0.025	0.02	0.018
Rh	<0.01	<0.01	<0.01	<0.01	<0.01
Pd	0.06	0.11	0.25	0.015	0.02
Ag	0.38	2.62	0.82	0.15	0.28
Os	<0.02	<0.02	<0.02	0.02	<0.02
Ir	<0.01	<0.01	0.01	<0.01	<0.01
Pt	0.03	0.07	0.17	0.12	<0.02
Au	0.05	0.08	<0.02	<0.02	0.03

Note: (A18/2) Low-grade magnetite quartzite; (B18/2) carbonaceous ore-barren quartzite; (B18/2U) graphite-bearing floatation product from sample A18/2; (A18/4) hematite–magnetite quartzite; (B18/4) low-grade magnetite quartzite. Contents of elements were determined by the ICP-MS method.

Table 2. Contents of Pt, Pd, and Au in primary ferruginous quartzites and some technological products (g/t)

Samples and their technological products		Pt	Pd	Au	Samples and their technological products		Pt	Pd	Au
A18/2	1	0.013	0.019	0.030	A18/4	1	0.021	0.014	0.050
	2	0.88	0.36	2.1		2	0.2	0.3	0.9
	3	0.02	0.08	0.03		3	0.08	0.03	0.12
	4	0.05	0.09	0.11		4	0.09	0.05	0.17
	5	<0.01	<0.01	0.015		5	<0.01	<0.01	0.02
B18/2	1	0.035	0.035	0.100	B18/4	1	0.008	0.008	0.012
	2	1.2	1.2	3.2		2	0.05	0.04	0.31
	3	0.1	0.23	0.045		3	0.02	0.02	0.02
	4	1.17	1.17	3.10		4	0.023	0.022	0.052
	5	<0.01	<0.01	0.02		5	<0.01	<0.01	<0.01

Note: Technological products: (1) initial sample, (2) nonmagnetic fraction, (3) magnetic fraction; (4) gravitational concentrate; (5) gravitational tailing.

on the one hand, and to develop optimal technologies for the dressing of ores and extraction of PGEs and Au from them, on the other hand, we took two technological samples (30 kg each) from sulfidized hematite–magnetite and magnetite-rich zones of the Lebedyan open pit. The samples of sulfidized ferruginous quartzites were taken at the contact with intraore carbonaceous shales. Samples with numeral designation 18/2 were taken from the 30-m bench (at the contact with the lower ore-bearing subformation), while samples with numeral designation 18/4 were taken from the 0-m bench between ore-bearing shales. The samples were subsequently divided into two portions with letter designations A and B. Results of the determination of noble metals in them are given in Table 1.

The samples were processed and concentrated according to the conventional procedure applied for the dressing of ferruginous quartzites [4, 5]. After grinding up to a <0.5-mm size, the samples were subjected to gravitational and magnetic separation. One portion of the gravitational concentrate was used to determine concentrations of noble metals by the test tube method in initial ferruginous quartzites and their technological products, the nonmagnetic fraction and gravitational concentrate of which showed very high (2–5 to 400 times or more) concentrations of Pt, Pd, and Au (Table 2).

Local microprobe analysis of samples prepared from the second portion (ultraheavy concentrate) revealed for the first time that the ferruginous quartzites include significant concentrations of PGMs, such as native ruthenium and osmium, minerals of the Os–Ru–Ir and Ru–Pt–Rh series, prassoite (or miassite), and sperrylite. Their chemical compositions and crystallochemical formulas are presented in Table 3, while their modes of occurrence are illustrated in Fig. 1.

The PGMs associate with the widespread high-standard native gold that makes up typical intergrowths with native silver, Au–Ag alloy, petzite, hessite,

Table 3. Chemical compositions of platinum group minerals in ferruginous quartzites of the Lebedyan deposit, wt %

Ord. no.	Pt	Pd	Ir	Os	Ru	Rh	As	S	Fe	Ni	Total	Crystallochemical formula
Sulfidized hematite–magnetite quartzite (A18/4)												
1	8.52		31.4	39.94	17.78	1.29			0.31	0.42	99.66	$Os_{0.34}Ru_{0.28}Ir_{0.26}Pt_{0.07}Rh_{0.02}Fe_{0.01}Ni_{0.01}$
2	9.23		31.33	45.58	12.71	0.75					99.60	$Os_{0.41}Ir_{0.28}Ru_{0.22}Pt_{0.08}Rh_{0.01}$
3	44.50		7.61	8.13	27.38	9.43			1.44	0.60	99.09	$Ru_{0.38}Pt_{0.32}Rh_{0.13}Ir_{0.06}Os_{0.06}Fe_{0.04}Ni_{0.01}$
4	5.11				1.86	72.35		20.56			99.88	$(Rh_{16.45}Pt_{0.61}Ru_{0.43})_{17.49}S_{15.00}$
5	21.39		34.25	22.45	18.65	0.67			1.87		99.28	$Ru_{0.29}Ir_{0.28}Os_{0.19}Pt_{0.17}Fe_{0.05}Rh_{0.01}$
6	56.4						43.6				100.0	$Pt_{0.99}As_{2.00}$
7	55.4						43.3	0.8			99.5	$Pt_{0.98}(As_{2.00}S_{0.05})_{2.05}$
Carbonaceous ore-barren sulfidized quartzite (B18/2)												
8	19.94		20.75	15.14	41.97	0.66			0.53		98.99	$Ru_{0.58}Ir_{0.15}Pt_{0.14}Os_{0.11}Rh_{0.01}Fe_{0.01}$
9	51.24	0.73			0.63	5.14	42.79				100.53	$(Pt_{0.92}Rh_{0.17}Pd_{0.02}Ru_{0.02})_{1.13}As_{2.00}$
10	1.2		19.12	77.76	1.4						99.48	$Os_{0.77}Ir_{0.19}Ru_{0.03}Pt_{0.01}$
11	13.7	0.7	24.92	13.48	46.38	0.63					99.81	$Ru_{0.64}Ir_{0.18}Os_{0.10}Pt_{0.06}Pd_{0.01}Rh_{0.01}$
12	56.80						41.20	0.80	0.40		99.20	$(Pt_{1.01}Fe_{0.02})_{1.03}(As_{1.91}S_{0.09})_{2.00}$
13	56.7						42	0.5	0.5		99.7	$(Pt_{1.01}Fe_{0.03})_{1.04}(As_{1.95}S_{0.05})_{2.00}$

Note: (1, 2) Minerals of the Os–Ru–Ir series; (3) minerals of the Ru–Pt–Rh series; (4) prassoite; (5) mineral of the Ru–Ir–Os–Pt series; (6, 7) sperrylite; (8) native ruthenium; (9) sperrylite; (10) native osmium; (11) native ruthenium; (12, 13) sperrylite.

Table 4. Chemical compositions of native gold and associated Au–Ag–Te–Bi minerals in ferruginous quartzites of the Lebedyan deposit, wt %

Ord. no.	Au	Ag	Fe	Cu	Te	Bi	Total	Crystallochemical formula
Sulfidized low-grade magnetite quartzite (A18/2)								
1	97.30	1.57	–	1.37	–	–	99.24	$Au_{0.96}Ag_{0.03}$
2	94.35	5.42	–	–	–	–	99.77	$Au_{0.91}Ag_{0.09}$
3	93.98	2.63	–	2.33	–	–	98.94	$Au_{0.89}Ag_{0.05}Cu_{0.07}$
4	81.34	19.32	–	–	–	–	100.66	$Au_{0.70}Ag_{0.30}$
5	98.23	1.02	–	–	–	–	99.2	$Au_{0.98}Ag_{0.02}$
6	96.97	2.06	0.20	0.80	–	–	100.03	$Au_{0.93}Ag_{0.04}Fe_{0.01}Cu_{0.02}$
7	63.80	35.60	0.43	–	–	–	99.83	$Au_{0.49}Ag_{0.50}Fe_{0.01}$
8	25.68	40.68	0.28	–	32.89	–	99.73	$(Ag_{2.94}Au_{1.01}Fe_{0.04})_{3.99}Te_{2.00}$
Carbonaceous ore-barren sulfidized quartzite (B18/2)								
9	95.05	4.58	–	–	–	–	99.63	$Au_{0.92}Ag_{0.08}$
10	1.30	–	–	–	38.67	59.45	99.42	$Te_{0.51}Bi_{0.48}Au_{0.01}$
11	23.64	42.08	–	–	32.21	–	99.93	$(Ag_{3.09}Au_{1.03})_{4.12}Te_{2.00}$
12	1.71	61.09	–	–	34.90	2.32	100.02	$(Ag_{1.99}Au_{0.03})_{2.02}(T_{0.96}Bi_{0.04})$
13	82.54	12.36	–	5.62	–	–	100.52	$Au_{0.67}Ag_{0.18}Cu_{0.14}$
14	94.36	5.64	–	–	–	–	99.96	$Au_{0.90}Ag_{0.10}$
15	95.70	4.26	–	–	–	–	99.96	$Au_{0.92}Ag_{0.08}$
16	89.57	9.96	–	–	–	–	99.53	$Au_{0.83}Ag_{0.17}$
17	87.87	6.31	–	5.77	–	–	99.95	$Au_{0.75}Cu_{0.15}Ag_{0.10}$
Sulfidized hematite–magnetite quartzite (A18/4)								
18	88.71	11.35	–	–	–	–	100.06	$Au_{0.81}Ag_{0.19}$
19	84.85	3.65	–	11.56	–	–	100.06	$Au_{0.67}Cu_{0.28}Ag_{0.05}$
20	95.23	2.14	0.36	2.30	–	–	100.03	$Au_{0.89}Cu_{0.07}Ag_{0.04}Fe_{0.01}$
21	88.24	11.67	–	–	–	–	99.91	$Au_{0.81}Ag_{0.19}$

Note: (1–6) Native gold; (7) Au–Ag alloy; (8) petzite; (9) native gold; (10) tsumoite; (11) petzite; (12) hessite; (13, 14) native gold associated with chalcopyrite and magnetite; (15–21) native gold with traces of Ag, Cu, and Fe.

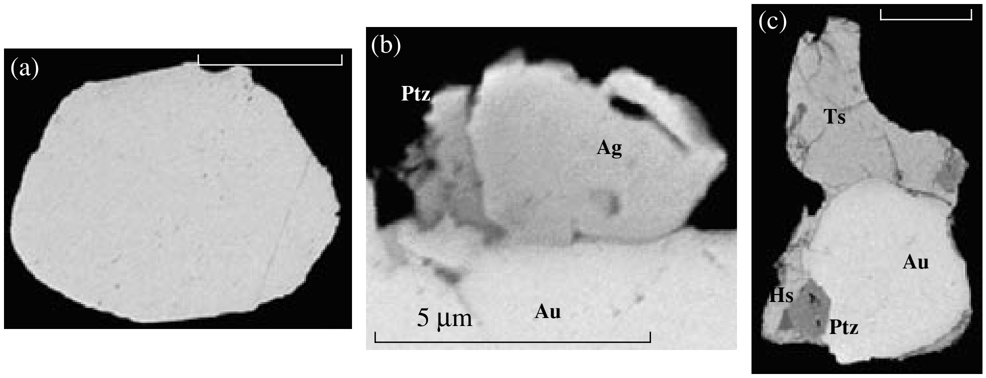

Fig. 2. Modes of occurrence of gold and its intergrowths with other minerals. (a) Native gold; (b) intergrowths of native gold (Au), silver (Ag), and petzite (Ptz); (c) intergrowth of native gold (Au) with a rim of tsumoite (Ts), petzite (Ptz), and hessite (Hs).

tsumoite (Table 4, Fig. 2), chalcopyrite, and, occasionally, magnetite.

In addition to individual mineral phases, PGEs and Au also occur in the following sulfides and their analogues (concentrations of elements are given in wt %): pyrite (Pd 0.01–0.10, Pt 0.02–0.38, Au 0.02–0.62); pyrrhotite (Pd 0.01–0.12, Pt 0.01–0.44, Au 0.09–0.51); chalcopyrite (Pd 0.01–0.11, Pt 0.07–0.39, Au 0.02–0.27); galena (Pd up to 0.43, Pt 0.31–0.37, Au 0.06–0.22); bismuth telluride (Pt 1.28, Au 0.27); bornite (Pd up to 0.14); tennantite (Pd 0.08); and arsenopyrite (Pt 0.18).

New data on the mode of occurrence of PGEs and Au make it possible to choose the optimal technology for the extraction of noble metals from ferruginous quartzites of the KMA and their technogenic products can also be used for the extraction of other byproducts that can serve as a unique (large-scale) source of gold–platinum ores in central Russia.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research (project nos. 04-05-64888 and 05-05-96408 tschr) and the "Universities of Russia" Foundation (project no. 324-05).

REFERENCES

1. N. I. Golivkin, N. D. Kononov, V. P. Orlov, et al., *Iron Ores of the KMA* (Geoinformmark, Moscow, 2001) [in Russian].
2. V. G. Lazarenkov, S. V. Petrov, and I. V. Talovina, *Deposits of Platinum Group Metals* (Nedra, St. Petersburg, 2002) [in Russian].
3. *Minerals of Noble Metals: Handbook*, Ed. by O.E. Yushko-Zakharova, V.V. Ivanov, L.N. Soboleva, et al. (Nedra, Moscow, 1986) [in Russian].
4. S. V. Petrov and V. A. Sentemova, Obogashchenie Rud, No. 6, 36 (1998).
5. N. M. Chernyshov, V. M. Izoitko, S. V. Petrov, and S. P. Molotkov, Dokl. Akad. Nauk **391**, 104 (2003) [Dokl. Earth Sci. **391**, 747 (2003)].
6. N. M. Chernyshov, *Platiniferous Formations of the Kursk–Voronezh Region, Central Russia* (Voronezh. Gos. Univ., Voronezh, 2004) [in Russian].
7. A. N. Shelekhov, V. A. Lyuchkin, and Yu. S. Lyakhovkin, Platinum of Russia: Problems of the Development of Raw Mineral Base of Platinum Group Metals in XXI Century, in *Collection of Scientific Works* (Geoinformmark, Moscow, 1999), pp. 289–294 [in Russian].
8. G. R. Olivo, M. Gaunter, and M. Bardoux, Miner. Mag. **58**, 579 (1994).