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## New Data on the Platinum Potential of Hydrothermal Formations in the Upper Amur Region

A. V. Mel'nikov<sup>a</sup>, S. M. Radomskii<sup>a</sup>,  
Academician of the RAS V. G. Moiseenko<sup>a</sup>, and V. D. Mel'nikov<sup>b</sup>

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Until recently, industrial deposits of platinum group elements (PGE) were only recognized in two petrogenetic classes. The magmatic class included liquation, early magmatic, and late magmatic deposits. The sedimentary class was represented by placers. Recently, they have been complemented with industrial deposits of Pt and PGE of metamorphic and hydrothermal classes. Deposits in black shales and their metasomatic rocks (unconventional or complex Au–Pt deposits [8]) have the highest Pt potential among these petrogenetic classes [2, 3, 12, 13]. Pt-bearing hydrothermal deposits are widespread in the upper Amur region. They have been explored over a long period and are characterized by significant resources.

Previously, the Pt potential was established in the beresite, beresite–listvenite, beresite–makerite, jasperoid, quartz–propylite, listvenite, makerite, skarn, tokurite, and khargite hydrothermal formations of the upper Amur region [6].

These hydrothermal formations have been investigated to varying degrees. Associations with beresites [5] and quartz–propylites [4] are best studied. Deposits in black shales [1], jasperoids, serpentinites, skarns, and rodingites are less studied [11].

In 2006, we investigated sample collections from a number of ore deposits and occurrences of various hydrothermal formations. The results obtained revealed new data on the Pt potential of the following formations.

In terms of ore productivity, *beresite-containing associations* are among the major ore-bearing rocks of continents. Previously, Pt potential was found in the Bam gold deposit and the Svetloe and Malo-Chukansk ore occurrences. In 2006, the contents of noble metals

were determined in the Berezit and Pioner deposits and in ore occurrences of the Apsakan group.

In the *Berezit deposit*, inversion voltampermetric analysis (IVA) detected the following elements (g/t): (1) quartz–sulfide aggregate (seven samples): Au 0.65–1.31, Pt 0.075–1.24, and Pd 0.01–0.47; (2) vein quartz with sulfides (three samples): Au 0.67–2.45, Pt 0.11–1.12, and Pd 0.01–0.19; (3) garnet–quartz–sericite metasomatite with sulfides (six samples): Au 0.76–2.22, Pt 0.22–1.26, and Pd 0.01–0.21; (4) garnet–quartz–sericite–K-feldspar metasomatite with sulfides (six samples): Au 1.22–4.55, Pt 0.55–1.45, and Pd 0.01–0.14.

In the *Pioner deposit*, the IVA method detected Au and PGE in the following rocks (g/t): (1) quartz–sulfide aggregate (seven samples): Au 0.05–1.31, Pt 0.0054–1.24, and Pd 0.008–0.47; (2) vein quartz with sulfides up to 30% (three samples): Au 0.2–2.16, Pt 0.031–3.32, and Pd 0.001–0.19; (3) vein quartz with sulfides up to 25% (six samples): Au 0.14–2.51, Pt 0.022–1.16, and Pd 0.002–0.21; and (4) silicified and sulfidized quartz diorites (five samples): Au 0.22–2.91, Pt 0.113–0.744, and Pd 0.0019–0.04.

Atomic absorption analysis (AAA) detected PGEs in different *ore occurrences of the Apsakan group* (g/t): Dess (Pt 0.22–0.85 and Pd 0.012–0.16), Serebryanyi Klyuch (Pt 0.14–0.73 and Pd 0.026–0.14), Sivakan (Pt 0.21–1.23 and Pd 0.11–0.22), Ernichnoe (Pt 0.15–1.07 and Pd 0.01–0.07), Apsakan (Pt 0.2–0.8 and Pd 0.05–0.1), Dominikan (Pt 0.11–0.49 and Pd 0.051–0.11), Nakhodka (Pt 0.21–0.31 and Pd 0.071–0.091), Klyuchikan (Pt 0.19–0.21 and Pd 0.038–0.16), Normandiya (Pt 0.25–0.81 and Pd 0.075–0.11), Glubokoe (Pt 0.35–0.44 and Pd 0.05–0.09), and Zagadka (Pt 0.38–1.16 and Pd 0.1–0.21).

The *quartzite–propylite formation* includes porphyry-type deposits and vein–metasomatic deposits of the volcanoplutonic type. In [7], the Pt potential was reported from the Pokrov deposit and the Solnechnoe, Deniska, and Ezop ore occurrences. In 2006, we investigated the Borgulikan and Burinda deposits.

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<sup>a</sup> Institute of Geology and Nature Management, Amur Scientific Center, Far East Division, Russian Academy of Sciences, per. Relochnyi 1, Blagoveshchensk, Amur oblast, 675000 Russia; e-mail: anton\_amur@mail.ru

<sup>b</sup> Amur State University, Ignat'evskoe sh. 21, Blagoveshchensk, 675029 Russia

In the *Borgulikan porphyry Cu–Mo deposit*, the IVA method detected Pt in the following hydrothermal rocks: (1) 0.22–4.27 g/t in the sulfidized quartz–sericite metasomatites, (2) 0.21–4.55 g/t in the propylitized volcanic rocks with stringer-veinlet sulfide mineralization, and (3) 0.51–5.2 g/t in the sulfidized quartz veins.

In the *Burinda deposit*, the IVA and AAA methods detected PGEs in the following rocks (g/t): (1) vein quartz with sulfides (Pt 0.02–0.78 and Pd 0.096–0.11), (2) sulfidized propylites formed after andesites (Pt 0.022–0.49 and Pd 0.05–0.11), (3) quartz–carbonate aggregate with sulfides (Pt 0.07–0.21 and Pd 0.28–0.35), and (4) quartz–sericite veinlets with sulfides (Pt 0.11–0.62 and Pd 0.11–0.27).

The *makerite formation* includes metasomatites formed after metamorphic rocks (makerites) and associated hydrothermal bands of different compositions [7]. The deposits of this formation are widespread among metamorphic complexes of the Stanovoi plutonometamorphic zone. Previously, Pt potential was detected in the Odolgo, Kipuchi, and Strelka ore occurrences. In 2006, we investigated the Zolotaya Gora and Uspenskoe hydrothermal deposits, as well as the Dorozhno-Goratsiev and Vershinno-Goratsiev ore occurrences.

In the *Zolotaya Gora deposit*, the IVA method detected PGEs in the following hydrothermal rocks (g/t): (1) quartz–sericite–muscovite schists with sulfides (Pt 0.46–0.83 and Pd 0.032–0.10) and (2) vein quartz with spotty–stringer–disseminated sulfide mineralization (Pt 0.33–0.76 and Pd 0.012–0.112).

In the *Uspenskoe deposit*, the IVA method detected the following elements (g/t): Pt 0.112–0.91 and Pd 0.022–0.078. In quartz–feldspar and carbonate–quartz veins with sulfides, the contents of Pt and Pd are 0.112 and 0.015 g/t, respectively.

In the *Dorozhno-Goratsiev ore occurrence*, the AAA method detected PGEs in the following rocks (g/t): (1) quartz-rich hydrothermal rocks with sulfides (Pt 0.11–0.77 and Pd 0.028–0.083) and (2) silicified and ferruginated gneisses with sulfides (Pt 0.355–0.37 and Pd 0.0123–0.047).

In the *Vershinno-Goratsiev ore occurrence*, the AAA method detected PGEs in the following rocks (g/t): (1) quartz-rich hydrothermal rocks with sulfides (Pt 0.18–0.38 and Pd 0.012–0.12) and (2) silicified and ferruginated microgabbro and amphibolites with sulfides (Pt 0.20–0.46 and Pd 0.023–0.032).

The Pt-bearing *skarn formation* is represented by the Gar'sk iron ore deposit, as well as the Tachtamygda, Skarnovoe, Kokrazov, and Zieskie Vorota ore occurrences. In 2006, we investigated the Igak and Orel ore occurrences.

In the *Igak ore occurrence*, the AAA method detected the following elements in dumps of vein quartz and magnetite ores of skarns (g/t): Pt up to 0.655, Pd up to 0.121, Ir up to 0.044, Os up to 0.061, and Rh up to 0.011.

In the *Orel ore occurrence*, the AAA method detected the following elements in skarnized limestones and skarns (g/t): Pt 0.088–0.412, Pd 0.083–0.103, Ir 0.022–0.036, Os 0.011–0.042, Ru <0.05, Rh 0.008–0.01, Au up to 5, and Ag up to 700.

The *tokurite association* (hydrothermal carbonaceous quartz and sulfide–quartz rocks formed after black shales) is among the most widespread type of rocks in the upper Amur region [7]. Previously, Pt potential was found in the Malomyr, Tokur, and Yasnoe deposits, as well as the Baldygliya, Belen'koe, and Schastlivoe ore occurrences.

In 2006, we studied the *Voroshilov deposit* by the AAA method and revealed the following elements in bulk specimens of quartz–mica schists with abundant dissemination of arsenopyrite, chalcopyrite, and galena (g/t): Pt 0.06–0.94, Pd 0.014–0.028, Ir <0.1, Rh <0.1, Os 0.006–0.01, and Ru 0.001–0.041.

The *khargite association* includes hydrothermal rocks formed after greenschists. Previously, Pt potential was discovered in the Khargin, Afanas'ev, and Sagur deposits, as well as in the El'ga ore occurrence.

In the *Unglichikan gold–tungsten deposit*, the AAA method detected the following elements in bulk specimens of ore breccia composed of sulfidized and silicified fragments of schists, mudstones, and metasandstones with quartz cement (g/t): Pt 0.27–1.14, Pd 0.024–0.028, Ir <0.1, Rh <0.1, Os 0.008–0.036, and Ru 0.007–0.056.

## CONCLUSIONS

Thus, we have obtained new data on the Pt potential of the following hydrothermal rocks in the upper Amur region (ore deposits and occurrences are given in parentheses): beresite formation (Berezit, Pioner, and Apsakan group), quartz–propylite formation (Burinda and Borgulikan), makerite formation (Zolotaya Gora, Uspenskoe, Dorozhno-Goratsiev, and Vershinno-Goratsiev), skarn formation (Igak and Orel), tokurite formation (Voroshilov), and khargite formation (Unglichikan). It is necessary to assess the Pt potential of the massive sulfide formation (Kamenushin deposit and ore occurrences of the Solov'ev group). In other regions of Russia (Urals, Rudnyi Altai, the Far East, and the Northeast), sulfide ores of the copper, copper–zinc, copper–nickel, copper–cobalt, gold–sulfide, and other types of the massive sulfide formation contain economic concentrations of PGEs. Pt and Pd are constant constituents, whereas Rh, Ir, Ru, and Os are less common [9].

Taking into consideration the close relationship between the bedrock and placer mineralizations, it is essential to carry out special works devoted to investigation of the Pt potential of hydrothermal rocks in placer haloes of the Dambuka ore district, as well as in the Dep-Gar'sk, Solov'ev, Sugdzhar, and Urusha-Ol'doi ore-placer groups [10].

Analysis of Pt distribution in hydrothermal formations of the upper Amur region indicates a high Pt potential of hydrothermal bedrocks and associated placers in the majority of ore groups. For example, our calculations show that the Pt potential of hydrothermal bedrocks is three to four times higher than the approved prognostic resources of Pt and PGE.

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