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Chromite placer occurrences of the Volga-Ural basin – genesis, sources and industrial potential

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Abstract. Chromium is a strategic metal, but more than a half of Russia's needs are met by imports, so new deposits of chromites, including unconventional placer deposits, are of industrial and scientific interest. Previous studies and current works of the authors of the article have established the chromite placer metal content of Permian-Jurassic deposits of the Volga-Ural basin, which has industrial and potential significance: within the Lukoyanovsky placer area (Nizhny Novgorod region), the industrial chromite content of Jurassic coastal-marine titanium-zirconium placers has been established; in the south-west of Bashkiria, chromite-bearing sands (Sabantuy occurrence) with increased contents, but not yet clear industrial potential. The study of the typomorphism of chromites indicate their close relationship with the chrome spinel of ophiolite associations. The assumed overthrust structure of chromite-bearing hyperbasites of the Urals suggests a wide distribution of chromite-bearing sands within the Upper Permian-Jurassic Volga-Ural paleobasin, in which the increased content of chromites was controlled by hydro- and lithodynamic conditions favorable for placer formation. Questions of the genesis of chromite placer occurrences in the Ural part of the East European Platform, their distribution and primary sources need further study.

Keywords: chromites, placer deposits, strategic metals, Volga-Ural basin

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Introduction

Chromium is included in the list of major strategic metals in Russia and is stored in the reserves of many foreign countries (Order of the Government of the Russian Federation On the list of the main types of strategic mineral raw materials ..., 1996; Kremenetsky, 2020). State balance of mineral reserves of the Russian Federation accounted for 52.1 million tons of chromite reserves of categories A+B+C_1+C_2, mainly in magmatogenic ores. The deposits of the Sarany group of chrome boulder placers in the Perm Territory consists of 8 objects with total reserves 245 thousand tons accounted in categories B+C_1, and 39 thousand tons in category C_2. Unbalanced reserves contain 90 thousand tons (Bykhovsky, Sporykhina, 2013). Approximately 85 thousand tons of chrome ores were mined in 2020 (12.5 % all-Russian production) (Government report, 2020). Reserves ilmenite, leucoxene and chromite and contained in them oxides (TiO_2 and Cr_2O_3) of Itmanov chromite-ilmenite-zircon placer (Nizhny Novgorod region) are classified as off-balance by technological properties. Off-balance reserves of chromite in balance reserves of ore sands amount to 663.05 thous. tons, or 296.8 thousand tons of Cr_2O_3.

594 thousand tons of chromite mined in Russia in 2019 covered 43.6 % of the country's needs, while the import of chrome concentrates amounted to 903 thousand tons, mainly from Kazakhstan (Government report, 2020). Taking into account the the deficit of chromium ores in Russia and the fact that geological exploration does not compensate for the extraction of this raw material, the discovery of new, including unconventional, chromite deposits may be of interest to the industry.

This type of deposits can be chromite-bearing sands found within platform areas in the marginal parts of folded structures, as a component of distant complex coastal-marine and alluvial placers of heavy minerals, and actually proximal chromite placers, directly related to primary sources.

The study of these deposits and the assessment of their potential is carried out by identifying the main factors for the formation of high chromite metal content, as well as the creation of geological and genetic predictive and

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prospecting models of sedimentary (placer) deposits of chromite sands.

Potentially significant objects include the Jurassic titanium-zirconium sands of the Lukoyanovsky placer area, the intermediate hosts for which is the sandy deposits of the Urzhum stage of the Permian system, and the chromitolites of the Upper Kazan deposits of the southwestern Bashkiria

Geological structure and primary metal content of deposits and occurrences of chromite sands

Within the Volga-Ural sedimentary basin, the chromite content of sedimentary deposits was established within two objects that differ in stratigraphic, genetic, spatial, and lithological-mineralogical properties – the Lukoyanov placer area of the Nizhny Novgorod region and the Sabantuy placer occurrence in the south-west of Bashkiria (Fig. 1).

Lukoyanov chromite-ilmenite-zircon deposit

Within the Gaginsky, Lukoyanovsky, Shatkovsky, Pochinkovsky and Pervomaisky districts of the Nizhny Novgorod region, commercial titanium-zirconium placers of coastal-marine genesis have been identified in the deposits of the Bathonian stage of the Lower Jurassic (Placer mineral deposits of Russia..., 1997). The Lukoyanov deposit of titanium-zirconium sands, the richest in zircon content in Russia and the second in the world (after the Australian Atlasbuna Narring placer with a content of 17.4 kg/m^3) (Patyk-Kara, 2008), is a system of spatially and structurally separated deposits, from of which only the Itmanov placer has been explored in detail and is on the state balance sheet. The reserves of zirconium dioxide in the Itmanov placer amount to 388.9 thousand tons. with a content of 12.9 kg/m^3. The reserves of titanium dioxide (ilmenite, leucoxene and rutile) are estimated at 166.7 thousand tons with a content of 5.5 kg/m^3.

A distinctive feature of the Itmanov placer is high content of chromium oxide Cr_2O_3 (9.9 kg/m^3), the estimated reserves of which are 296.8 thousand tons (Bykhovsky, 2010)[1].

In the suurounding area of the Itmanov placer, at a distance of 15 to 40 km, there are other placers of the Lukoyanov titanium-zirconium region, the geological evaluation work on which has been brought to the stage of predictable resources of a high degree of reliability of category P_1, which for the entire Lukoyanov placer region are estimated at 573 thousand tons chromium oxide (Bochneva, Chefranov, 2019). The depth of the ore bed varies from 0 to 20 m (Fig. 2, 3).

Chromespinels in the placer are represented by chromite and, given the high magnesium content, chromopicotite (Mg, Fe)(Cr, Al)$_2$O$_4$. Variations in the composition of grains of this component are very significant (in % by weight): Cr_2O_3 30.9–59.0; Al_2O_3 13.1-43.0; FeO 15-24.6; Fe_2O_3 0.1–16.0; MgO 4.8–15.5. Chromite grains have a predominantly uniform chemical composition in volume, medium and poor roundness (Fig. 4).

For a long time, there was a problem of the technology of enrichment of ore sands of the Itmanov placer due to the impossibility of obtaining high-quality ilmenite concentrate from the collective ilmenite-chromite-hematite (IHG) product due to the close physical properties of the minerals (density, electrical conductivity, magnetic susceptibility). Therefore, the reserves of IHG- products were classified as off-balance in terms of technological properties. Recent studies have made it possible to find technological solutions that provide the possibility of processing more than 70 % of

[1]Bykhovsky L.Z. (2010). Report. Development of a feasibility study for permanent conditions, calculation of reserves of titanium-zirconium sands of the Itmanovskaya placer of the Lukoyanovskoye deposit in the Nizhny Novgorod region (as of 01.06.2010). VIMS, 2010.

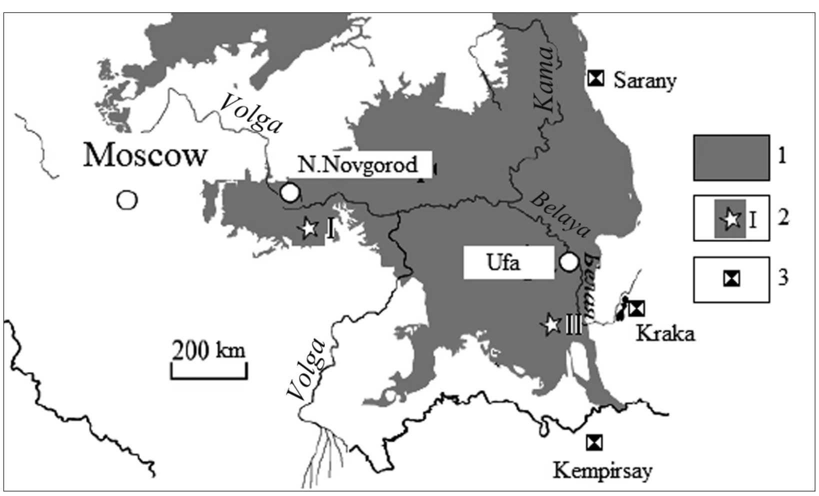

Fig. 1. Scheme of placer and bedrock occurrences of chromites in the Urals and the Volga-Ural basin. 1 – appearing of Permian deposits; 2 – placer occurrences of chromites in the sedimentary cover: I – Lukoyanov, II – Sabantuy; 3 – the main chromite deposits and hyperbasite massifs of the Urals (Sarany, Kraka, Kempirsay).

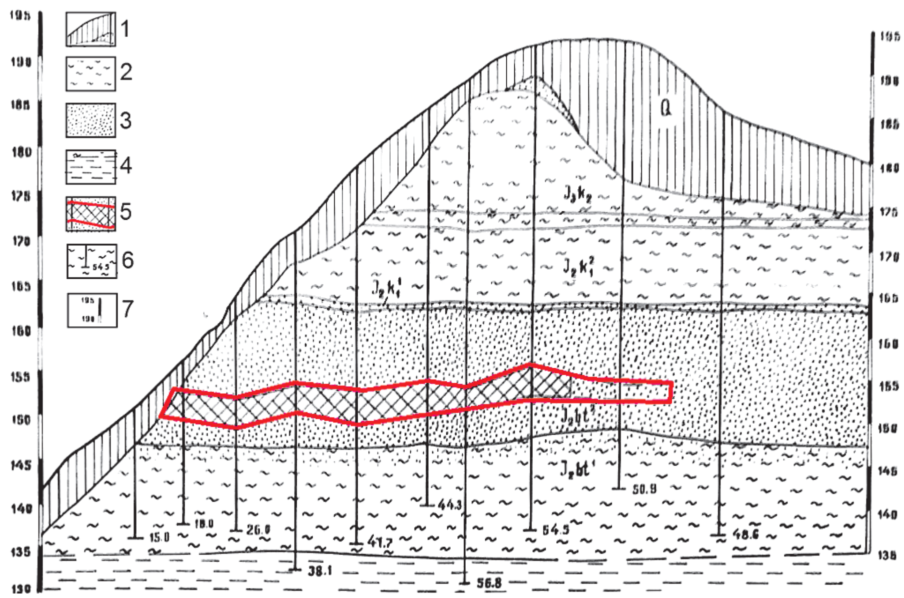

Fig. 2. Geological section of the Itmanov placer of the Lukoyanov titanium-zirconium deposit (Osipov, 1975)[3]. 1 – soil and vegetation layer; 2 – clay; 3 – sand; 4 – silt; 5 – industrial layer; 6 – wells (depth, m); 7 – elevation marks. Middle Jurassic deposits: J_2bt – Bathonian stage; J_2k – Callovian stage.

Fig. 3. Productive layer of the Itmanovs placer: dark interlayers contain increased concentrations of ore minerals – ilmenite, chromite and zircon

the IHG product into conditioned ilmenite and chromium concentrates (Zanaveskin et al., 2014).

It is assumed that chromites were redeposited into the Jurassic placer from the underlying Permian sandstones of the Urzhum stage (Gurvich and Bolotov, 1968; Bykhovsky, 2010). The source of chromites in the Permian deposits has not been investigated.

Sabantuy chromite occurrence

The Sabantuy chromite occurrence was revealed in the section of the Upper Kazan deposits, fragmentarily exposed in the left bank of the creek Small Berkutla at the northern end of the village Fedorovka, Fedorovsky district of the Republic of Bashkortostan (Rakhimov et al., 2020). In physical and geographical terms, the area is the southern flank of the Bugulma-Belebey Upland of the East European Platform (EEP). The geological section is represented by polymictic sandstones with interlayers of sandy silicified limestones (lower unit with a thickness of at least 20 m) and calcareous-sandy marls (upper unit with a thickness of up to 3 m) – rocks attributed to the Belebey Formation (P_2bl) (Knyazev, 2011). Sedimentary rocks of the Middle-Late Paleozoic and Riphean age lie below (Sinitsyn, Sinitsyna, 1965)[2].

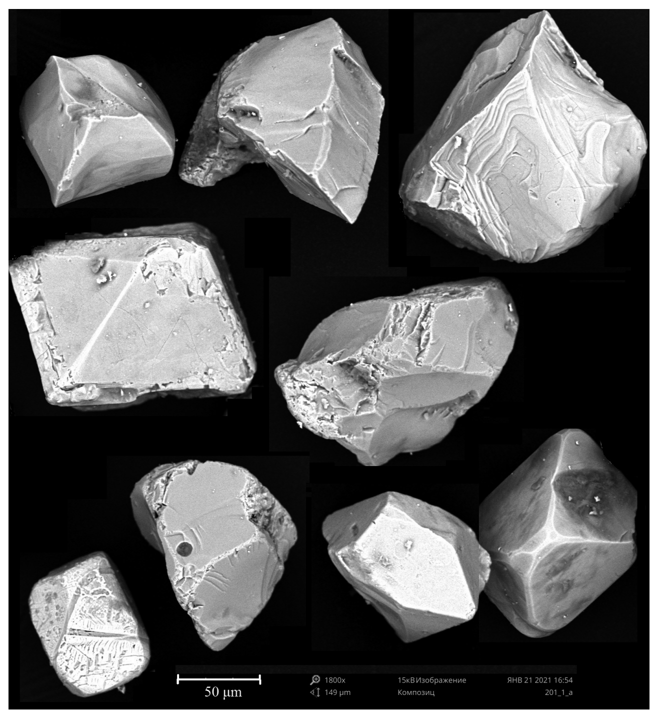

Fig. 4. Morphology of chromite grains of the Itmanovskaya placer

[2] Sinitsyn I.M., Sinitsyna G.I. Explanatory note to the geological map of the USSR on a scale of 1: 200000, Sheet No. 40-XXVI. M.: Ministry of Geology BTGU, V. 1, 1965. 170 p.

[3] A.P. Osipov (1985). A report on prospecting and appraisal works within the central part of the Lukoyanov titanium-zirconium deposit (Itmanov deposit) in the Lukoyanov district of the Gorkovskaya oblast, carried out by the Lukoyanovskaya GPP in 1982-85. Gorky: Lukoyanovskoe GPP.

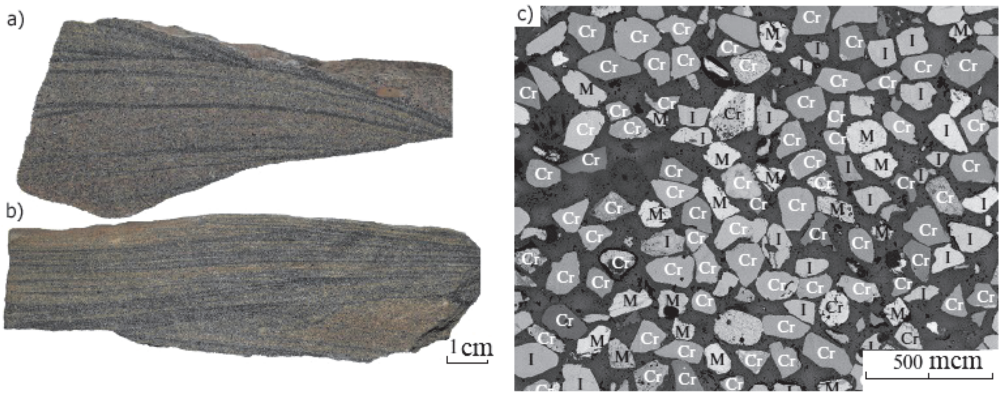

Fig. 5. Chromite sandstones of the Sabantuy placer occurrence: a) interlayers of chromitolites with oblique bedding; b) interlayers of chromitolites with gently undulating bedding; c) electron microscopic BSE image of chromitolite. Cr – chrome spinel, M – magnetite and titanomagnetite, I – ilmenite (Rakhimov et al., 2020).

Chromite sandstones are found in the form of eluvial fragments of block size along the slope for 200–250 m along the NW azimuth of 350°. The chromite layer was opened by a pit at a depth of 0.7 m from the surface and amounted to about 1 m. The texture of the deposits is layered, obliquely wavy and gently wavy, emphasized by an increased concentration of chromites. Ore layers (continuous chromitolites) vary in thickness from 1 to 130 mm.

The clasts of polymictic sandstones are dominated by quartzites (35 %), metavolcanites (32 %), and spinels (17 %). The sandstone cement is carbonate, in structure – pelitomorphic or fine-grained contact type. In terms of granulometric composition, graywackes correspond to medium-grained (size class 0.2–0.4 mm), and chromitolites correspond to fine-grained (0.15–0.25 mm) varieties of sandstones, they are characterized by a good degree of sorting. In terms of geological and lithological conditions and structural and textural features, the Sabantuy ore occurrence of chromites can be attributed to the type of coastal-marine placers. The terrigenous material of the sediments is well sorted, they are characterized by oblique and gently undulating bedding with distinct interlayers of highly concentrated ore interlayers – chromitolites. Grains of ore minerals have a poorly rounded or medium rounded shape; their size corresponds to the class of 0.15–0.25 mm. These features are characteristic of sediments formed in the littoral zone (Berthault et al., 2011; Lalomov, Tabolich, 2013).

The heavy fraction contains minerals of the spinel group (mainly Cr-spinels) (up to 67 %), ilmenite (17 %), magnetite and titanomagnetite (16 %). In single values, there are grains of other minerals – zircon, titanite, garnet, amphibole. The yield of the heavy fraction in chromitolites varies from 52 to 69 %, and in interbedded polymictic sandstones – up to 12 %. The total content of Cr_2O_3 is 15.9–17.2 wt. %. Primary ores with such grades are considered "poor" (Government report, 2020), but given their low lithification, location in an accessible area, and the possibility of open-pit mining, their industrial significance may be higher.

An analysis of the compositions of detrital spinels using the classification diagrams Al^{3+}–Cr^{3+}–Fe^{3+} and Mg# –Cr# in order to establish the formational affiliation of their sources showed that Cr-spinels of the Sabantuy ore occurrence correspond to Cr-spinels of ophiolite associations (Rakhimov et al., 2020). The compositions of the studied grains completely overlap with the compositions of Cr-spinels of the largest ophiolite complex in the Southern Urals – the Kraka massif (Saveliev et al., 2016). The studied Cr-spinels exhibit a negative correlation between chromium and Mg, which is a characteristic feature of endogenous spinels from ultramafic ophiolite complexes (Barnes, Roeder, 2001).

The source of the demolition of the Sabantuy chromite paleoplacer is still very difficult to establish from the available data. It is difficult to imagine that the source could be completely destroyed at present "local" protrusions of hyperbasites, since there are no direct traces of their former presence, for example, in the form of relics of weathering crusts (nontronite, montmorillonite) or indicator placer minerals (olivine, pyroxenes, platinum-metal and etc.) in the studied sediments. Considering the significant remoteness of the revealed ore occurrence, the high concentration of Cr-spinels in the studied sediments up to the formation of continuous layers of chromitolites, the weak roundness of the grains, as well as the limited distribution of the Sabantuy paleo placer, seriously consider the ophiolite complexes of the folded Urals (the nearest massifs, Kraka and Kempirsay, as a feeding province is also hardly possible. Such a distant transfer of spinels (over a distance of more than 200 km) with the formation of ore concentrations is not observed anywhere in the world (Kukharenko, 1961; Monograph ..., 2013). So, Cr-spinel placer located in the delta of the river. The reptile on the west coast of India is "rounded to sub-rounded" at a transport distance of 30–40 km (Gujar et al., 2010), in contrast to the poorly and non-rounded Sabantuy grains.

In the placer of the Gad River, (as in other predominantly ilmenite placers of long-range drift), chromites are present in the form of an associated component in the content of 0.05 to 10.9 % of the heavy fraction, and in the Bashkirian occurrence, in the heavy fraction of deposits, grains of minerals of spinels predominate, with Cr-spinels the main role belongs to (about 60 %).

A possible explanation for the phenomenon of the existence of near-drift chromite placers can be given on the basis of the overthrust model of the formation of hyperbasite massifs (Kazantseva et al., 1971; Puchkov, 2010). It can be assumed that the ophiolite allochthon may move far to the west from the zone of ophiolite sutures towards the East European platform (during the Permian orogenesis), closer to those morphostructural and lithodynamic settings that were favorable for the accumulation of chromite placers of the Sabantuy type (Rakhimov et al., 2020).

Thus, the revealed Sabantuy ore occurrence of chromites by a number of geological and lithological features is attributed to the type of coastal-marine placers with an age of P_2kz_2. To determine the exact parameters of ore occurrence and more informative geological features to identify the sources of drift, it is necessary to additionally study the Sabantuy occurrence and possible similar objects of the Volga-Ural basin.

Prospects for the chromite content of the sedimentary cover of the Volga-Ural basin

Thus, the chromite content of the Permian and Jurassic deposits of the eastern part of the East European Platform adjacent to the Urals was confirmed at least at two objects – the Lukoyanov placer and the Sabantuy occurrence. The industrial significance of the Lukoyanov chromites has been proven, the Sabantuy placer has good industrial prospects in terms of chromite content, but the spatial characteristics of the object are uncertain. As for the formation model of these objects, three types of chromite placers are known in the world: eluvial and eluvial-slope (in Africa, Cuba, the Philippines, including small boulder placers in the Middle Urals near the Sarany deposit), alluvial and coastal marine placers of near drift in valleys and near the coast, composed of chromite-bearing hyperbasites; the presence of Cr-spinels in the form of associated components in distal complex coastal-marine placers is also known (Patyk-Kara, 2002; Patyk-Kara, 2008; Ivanova et al., 2004; Sporykhina et al., 2016).

The Lukoyanov deposit belongs to distal offshore titanium-zirconium placers, but has its own characteristic features associated with an increased, to industrial, content of chromites. Obviously, this is due to the close proximity of a rich intermediate host, represented by the underlying Permian deposits of the Urzhum stage, which may be analogous to the Upper Kazan chromitolites of the Sabantuy. Taking into account the overthrust model of the formation of hyperbasite massifs, it can be assumed that chromite-bearing deposits are widespread within the Upper Permian Volga-Ural paleobasin. The predominantly submeridional direction of bottom currents with velocities up to 1.8 m/s (Lalomov et al., 2017) makes it possible to predict the presence of enriched meridionally oriented enriched zones and bands formed under favorable hydro- and lithodynamic conditions for placer formation, separated by deposits with background chromite contents. Estimating the distance of chromite transfer from the source to the placer formation zone, it is necessary to take into account the fragility of Cr-spinels, as a result of which, under active lithodynamic conditions, the roundness can decrease as a result of particle crushing. The close association of the chromites of the Urals with minerals of the platinum group makes it possible to increase the possible industrial significance of the supposed placer occurrences.

Conclusions

Chromium belongs to the list of strategic metal, but Russia's needs are less than half satisfied rush at the expense of their own resources, so even unconventional chromite placer deposits are of industrial and scientific interest.

Permian-Jurassic deposits of the Volga-Ural basin are chromite-bearing. They are of industrial and potential significance: Lukoyanovsky placer cluster (Nizhny Novgorod region) has industrial chromite concentrations in the Jurassic coastal marine titanium zirconium placers; in the south-west of Bashkiria, in the deposits of the Kazan stage, chromite-bearing sands (Sabantui occurrence) has high contents chromites with not yet clear industrial potential.

Investigation of the typomorphism of chromites indicates on their close relationship with ophiolite chrome spinels associations. Supposed curly structure chromite-bearing hyperbasites of the Urals suggests a wide distribution of chromite-bearing sands within the Upper Permian-Jurassic Volga-Ural paleobasin, in which elevated chromite contents were controlled by favorable for placer deposits formation by hydro- and lithodynamic conditions.

Questions of the genesis of chromite manifestations, their distribution and primary sources require further study.

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