Udokan-Chiney ore-magmatic system, Russia

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Introduction. In the South framework of the Siberian platform there is an extra large metallogenic province. Many giant deposits of different genetic types are concentrated here: Udokan (Cu), Chiney (Ti-Fe-V, Pd-Cu), Katugin (Ta, Nb), Sulumat (Fe) etc. (Fig.1). Copper deposits are in the centre of our interest for the reason that 40 Mt of Cu were found in Kodaro-Udokan region. They are concentrated in different rocks. All deposits are subdivided into three genetic types which were formed since Proterozoic epoch till Late Mesozoic. The most part of them belongs to copper sandstone formation (Udokan deposit and its satellites – Krasnaya, Burpala, Sakinskoe, PR1), and residual part is concentrated in gabbro in Cu-Ni sulphide ores (Chiney massif and in some related intrusions, PR1). Quartz veins with noble metals and copper were discovered [3] in the nearest framing of the Chiney massif. They are hosted in terrigenous–carbonate rocks and form the Pravoingamakitskoe deposit. Native copper was found in basalts inside the Udokan ridge (Chukchudinsky graben) as well (Mz).

Fig.1. Schematic geological map of the the Kodaro-Udokan region. 1) Quaternary deposits; 2) volcanic rocks (N-Q); 3) sedimentary Vend-Cambrian deposits; 4) Lower Proterozoic carbonate-terrigenous rocks of the Udokan seria; 5) granite, Ingamakitskiy complex; 6) gabbro, Chineyskiy complex (massifs: I-Chiney, II –Mylove, III – Luktur); 7) granite, Kodarskiy complex; 8) granite, Kuandinskiy complex; 9) Main Dyke of the Udokan deposit; 10) Cu sandstone horizon in the Udokan deposit; 11) faults; 12) deposits: 1- Rudnoe, 2 - Kontaktove, 3 - Skvoznoe, 4 - Pravoingamakitskoe, 5 - Sakinskoe, 6 - Udokan, 7 - Klukvennoe, 8 - Luktur, 9 - Unkur; 13) railway station.

Commercial mineralization was found on a very local area. Position of magmatic deposits controlled by the same zone-concentric structures and general faults which determinate localization of Cu sandstones. Chemical compositions of different deposits are very similar (Cu >> Ni, Au, Ag, PGE). The forming of anomalous Cu concentration in this region can be explained by metals remobilization and redeposition at different stage of geological history. We have studied Chiney and Pravoingamakitskoe deposits in details.

Results. 1. Chiney massif. Internal structure. The Chiney massif is the most typical layered intrusion in Russia [1]. It is represented by interlayering horizons of gabbro-norite and titanomagnetite gabbro in its lower zone and gabbro and anorthosite in the upper zone. It is located in the south-western part of the Kodaro-Udokan trough among Cu-rich sedimentary rocks of the Udokan formation. The massif is situated on the Ingamakit and Chiney faults’ intersection. It is exposed in an area over 120 km² and has a thickness of about 3 km. But there
are a lot of geological and geophysical evidences of its very great volume existing in the past. It is impossible to estimate the total volume of parent magma now, because its effusive products are probably denuded, and the consanguinity of the Chiney pluton with the adjacentely located Luktur ultrabasic-basic intrusion is not proved. Nevertheless, both plutons are similar in some mineralogical and geochemical features: their rocks host titanomagnetite and sulfide mineralization and have similar REE patterns. The basic and ultrabasic rocks of the Luktur pluton are supposed to be the Mg-rich fraction of the parental melt. Gravimetric and magnetic geophysical data show that ultrabasic and basic rocks occur at shallow depths at the Chiney pluton and around it. These facts show the existence of huge magmatic system in Late Proterozoic [3].

**Fig. 2.** Schematic geological map of the Chineyskiy Massif. (1) Quaternary deposits; (2) Early Proterozoic deposits of the Udokan Group; (3) basaltic dikes of various ages; (4–11) rocks of the Chineyskiy Complex: (4) rocks of the gabbro-norite series, (5) anorthosites, (6) rocks of the leucogabbro series, (7) rocks of the titanomagnetite–gabbro series, (8) monzodiorites, (9) pyroxenites (xenoliths), (10) high-grade titanomagnetite ores; (11) layers of titanomagnetite ore in the leucogabbro series; (12) granite of the Ingamakitskiy Complex; (13) strike and dip symbols of layering; (14) Ingamakitskiy Fault; (14) boreholes and their numbers; (15) sampling sites and sample numbers. Ore deposits: (I) Magnitnoe, (II) Etyrko, (III) Rudnoe, (IV) Kontaktovoe.

The main features of the structure of the Chiney massif are following [1, 2]: 1) consecutive introduction of magmas of different composition; 2) stratification of different nature; 3) differently grade rhythmicity. The Chineysky massif is thought to have been produced by successive emplacement of magmas, which formed four rock groups. (I) The first group comprises large xenogenic blocks and xenoliths of pyroxenites (up to 80 m across), altered anorthosites, and gabbro. (II) The second rock group includes gabbroids with elevated contents of titanomagnetite, which are classified into a titanomagnetite gabbro (approximately 1.0 km thick) and a leucogabbro (up to 1.5 km) series. (III) Titanomagnetite takes immediate part in formation of thin layering and microrhythmicity (therefore these ores were named thin-layered; the iron-ore series)[]. The third rock group comprises norites and gabbro-norites, which are recognized as the norite series and whose rocks are exposed in the central block and occur near the bottom of the western and southwestern blocks. As a result, the bulk of the Chiney massif is composed of compositionally principally different rocks of the second and third groups, with the predominance of intratelluric plagioclase and magnetite crystals in the former case (gabbro-norite and leucogabbro series) and orthopyroxene in the latter one (norite series). (IV) The youngest rocks are magmatic breccias with a lamprophyre and gabbro-norite cement and lamprophyres, which compose sills (a few meters thick) near the bottom of the intrusion, dikes, and chimneys (a few meters in diameter) in the massif.

The major rock groups (second and third) exhibit clearly pronounced and variable layering. Its first type can be characterized as low-scale (from a few centimeters to a few decimeters)
layering due to variations in the contents of mafic minerals in the vertical sections of certain rock layers, which are usually closely similar to the bulk composition (so-called gravitational stratification [2]. It should be emphasized especially the presence of the rocks of titanomagnetite-plagioclase composition named chinites in the uppermost parts of layered units (series, macrorhythms, rhythms)

*Chiney deposits.* It is necessary to emphasize unique features of the Chiney layered massif because of the presence of copper and ferrotitanic ore deposits in its structure, since their combined occurrence is a rare phenomenon within the same intrusion. There are two types of commercial mineralization in the Chiney massif: Fe-Ti-V and Cu with precious metals. Nowadays the Chiney massif comprises the largest V resources in Russia. The iron ores are concentrated in the central part of the intrusion and are represented by two varieties: disseminated and massive (the early-magmatic type); veins and irregular bodies (the late-magmatic type).

Sulfide minerals occur as accessory disseminations in all rocks of the massif, but their higher concentrations are distributed locally. The copper commercial mineralization is confined to the contact zone of gabbroids with the host rocks, so endo-and exocontact ores are determined. The disseminated mineralization predominates sharply. Vein bodies are distributed in the limited region and localized at a small distance from the bottom of the intrusion.

The main ore mineral is chalcopyrite, that is very unusual for Cu-Ni deposits (Cu/Ni=10-100, Pd/Pt=3 in ores). The major minerals are pyrrhotite and pentlandite. Many rare minerals of noble metals (Ag, Au, PGE) were found too. In general, the minerals consist of compounds of Pd with Bi, Te, Sb, Sn, As, and Ni; compounds of Pt with As, S, and Fe; a compound of Rh with As-S, as well hessite (Ag$_2$Te) and Au-Ag-(Hg) alloys. It was found froodite; sobolevskite; kotulskite; sudburyite; stibiopalladinite; mertieite II; isomertieite; paolovite; michenerite; arsenopalladinite; merenskite; majakite; menshikovite; naldretteite; unnamed phases [4].

The Chiney massif typically encloses millerite–chalcopyrite veins and lenses of massive sulfides with an aureole of pyrrhotite–chalcopyrite dissemination. Exocontact sulfide ores are enriched in chalcopyrite, and in cobaltite-gersdorffite The subhorizontal ore zone is 3–65 m thick and 1–2 km long. Copper is the major metal, while Pt, Pd, Au, Ag, Ni, and Co are associated components. The ores are mainly characterized by a patchy–disseminated texture. Stringer and breccia-type textures are less common. The outer contact zone includes vein and lenticular bodies at the intersection of differently oriented fractures with anomalously high concentrations of noble metals (g/t): Pt 15, Pd 124, Au 14, and Ag 345. These elements do not correlate with Cu [3]. The magmatic nature of sulfur in sulfide minerals is indicated by its isotopic composition determined at the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry (L.P. Nosik, analyst). The $\delta^{34}$S value varies from $-2$ to $+7$‰.

2. *Pravongamakitke deposit.* Quartz veins with noble metals and copper were discovered in the nearest framing of the Chiney massif and the Pravoingamakitskoe deposit. Ore bodies of the Pravoingamakitskoe deposit are hosted in terrigenous–carbonate rocks of the middle section of the Chitkanda subformation of the Lower Proterozoic Udokan Formation. The discontinuous cupriferous horizon is traced as a NW-striking zone extending over nearly 10 km on the surface and 400–500 m along the dip. Economic grade mineralization is developed over 4.5 km. The deposit includes ore bodies of two types: (1) veins and lenses of milky white massive quartz with stringers and patches of sulfides (Fig. 2); (2) echelon of massive sulfide bodies surrounded by dissemination of pyrite and chalcopyrite. Quartz veins (0.3–1 m thick) extend along the strike over a few tens of meters. Sulfide bodies are 3–5 m thick and 300–440 m long. The ore bodies are characterized by significant content of Cu (0.47–2.5 wt %) and very high variation of the Cu/Ni ratio (from 10 to 700 in various sectors). Ores are represented by pyrite–chalcopyrite varieties with typical stringer and breccia structures (Fig. 2). The maximal concentration of Ni in quartz veins is related to high contents of nickel minerals (millerite and pentlandite). The quartz vein ore is also enriched in noble metals (g/t): Pt 0.1–2.2, Pd 0.9–6.2, and Au 0.1–0.4.
There were found fine grains of (up to 10 m) of clausthalite Pb$_{1.00}$Se$_{0.78}$S$_{0.22}$, hessite Ag$_{1.98}$Te$_{1.02}$, bravoite (Ni$_{0.73}$Fe$_{0.30}$)$_{1.03}$S$_{1.97}$, bogdanovichite AgBiSe$_2$, and palladium intermetallides, the composition of which could not be determined precisely because of their small dimension (a few micrometers).

The major ore minerals in these sectors are characterized by high concentrations of Ni and Co. In particular, their concentrations in pyrite are as much as 1.75 and 1.48 wt %, respectively.

In Cu-rich massive sulfide ores, the concentration of the majority of noble metals is appreciably higher (Pt-0.04, Pd-0.6, and Au-0.4 g/t) than in veins. However, the Ag concentration is maximal in the vein ore (as much as 371 g/t in some specimens). The major minerals of this ore type are characterized by lower contents of Ni and Co.

Conclusions. Analysis of area tectonic development and mineralogical-geochemical features of Cu ores from different deposits show that the Kodaro-Udokan copper belt can be explained as a result of numerous geological processes. The existence of gigantic magmatic system in the past was the main factor of Cu deposits’ formation due to the substance remobilization by basic-ultrabasic magmas from surrounding rocks.

Particularly copper composition and almost complete absence of nickel in the ores of the Chiney intrusion single out this massif among the basic-ultrabasic layered plutons comprising Cu-Ni deposits. It proves the connection of this ore type with previous stage of mineralization. Trace elements confirm this fact as well. So, Udokan deposit contains Ag and Au; some of its satellites belong to Cu-Au-Ag ones, while in Chiney massif high concentrations of precious metals are presented.

The geological position and specific features of the tectonic events and magmatism of the Udokan–Chiney ore district suggest that the metallogenic specialization of the South framework of the Siberian platform can be related to the processes of multistage tectonomagmatic reactivation. The first stage (~2 Ga ago) was marked by the formation of the Kodar–Udokan Trough with both sedimentary and synsedimentary hydrothermal sulfide mineralizations. Development of sedimentary hydrothermal mineralization in sedimentary basins has been recorded in various geotectonic settings, including the unique Witwatersrand Basin [3]. The second stage (~1.8 Ga ago) was related to ultramafic–mafic magmatism, the formation of the Chiney massif with magmatic ores, and the development of the postmagmatic hydrothermal quartz–sulfide mineralization with PGE. This stage was undoubtedly associated with the abyssal fluid-magmatic system. Tectonic displacements and significant erosion of the Southern part of the Siberian Platform after the Proterozoic epoch were responsible for the exhumation of blocks with various components composed of layered massifs of the Chiney complex. These processes promoted the formation of magmatic deposits of sulfide ores, hydrothermal copper deposits in their framing, and sedimentary copper deposits in the distal zone.

References