Geological structure and prospects of noble metal ore mineralization of the Khayrkhan gabbroid massif (Western Mongolia)

K R Kurumshieva, I F Gertner, P A Tishin

Department of Geology and Geography, Tomsk State University, Lenin Avenue 36, Tomsk, 634050, Russia

E-mail: kkurumsieva@gmail.com

Abstract. An analysis of the distribution of noble metals in zones of sulfide mineralization makes it possible to justify the isolation of four ore-bearing horizons with a specific geochemical zonation. A rise in the gold content relative to palladium and platinum is observed from the bottom upwards along the section of the stratified series of gabbroids. The study of the mineral phases of sulphides and the noble minerals itself indicates the evolution of hydrothermal solutions, which determines the different activity and mobility of the fluid (mercury, tellurium, sulfur) and ore (copper, nickel, iron, platinum, gold and silver) components.

The Khairkhan dunite-troctolite-anorthosite-gabbro massif is a part of the Bayantsagan range of peridotite-pyroxenite-gabbronorit intrusions of the Hirgiznur Early Paleozoic complex [1]. It is located in the central part of the Lake Zone of Western Mongolia and forms a large lenticular body (18×5 km^2), stretched in the north-west direction. This massif is one of the largest layered gabbroic plutons and composes the zone of bald mountains of the Bumbat-Khairkhan ridge (Jargalantu) (elevations of about 3000 m). In the northern part of the intrusion in the upper reaches of the Urtuin-Gol river gabbronorites break through dislocated schists, sandstones, siltstones and limestones, which on regional maps belong to the Lower Cambrian burgasutai series. The host rocks in contact experience hornfreezing and, occasionally, contact melting. Intrusive contact of gabbroids with a conglomerate layer is also observed near of the Shara-Bulak spring in the southern part of the massif. The eastern part of the Khairkhan massif is destroyed by a fault of the northwestern strike, through which the deposits of the Burgasutai suite are brought into contact with the various facies of the intrusion, broken by the multiphase intrusion of quartz diorites, granodiorites and granites of the Tokhogenshil Early Paleozoic complex. The western part of the intrusion is destroyed by a large massif of the same complex. Intrusive contacts of quartz diorites of the Tohtogenshil complex and gabbronorites of the endocontact facies of the Khairkhan massif were observed northwest of the Ulin-Daba pass. The gabbroids in contact are hornfels and uralitized, which strongly obscures the primary magmatic structures of gabbroids and makes their field diagnostics more difficult. This led some researchers to erroneous ideas about gradual transitions between the diorites of the Tokhtoghenshil complex and differentiated gabbroids [2-3]. Further researches of this massif indicate the intrusive nature of both gabbroids and quartz diorites, while the latter break through the rocks of the marginal facies and the stratified series of the Khairkhan massif.

The primary structure of the Khairkhan massif was disturbed by later folded processes and the introduction of the intrusive bodies of the Tokhogenshil diorite-granodiorite complex. Most of the massif on its northeastern flank is tectonically disintegrated. The dynamometamorphic transformation is

expressed in the tectonic character of the northeastern contact of the pluton with host Vendian-Early Cambrian volcanic-sedimentary deposits and in the development of isolated fragments of igneous rocks of a similar petrographic composition on the extension both along and across the main body. The intrusive bodies of the Tokhogenshil diorite-granodiorite complex on the southwestern flank cut the primary magmatic contact of the gabbroid series of the Khairkhan massif, making it difficult to estimate the true dimensions of the latter.

In the structure of the Khairkhan massif participate gabbroids of the stratified series and the marginal facies. The stratified series composes most of the pluton, mainly its central part. It is characterized by peri-magmatic stratification, differentiation and rhythmicity. The elements of the stratification are characterized by a northwest strike, consistent with the extent of the mass itself, and steep incidence angles. The stratified series is composed of plagioclase-containing dunites, troctolites, olivine gabbros, olivine gabbronorites, and anorthosites, with the most common troctolites and olivine gabbros. Ultrabasic rocks are widely distributed and occur at the base of the section, while anorthosites and leucocratic olivine gabbronorites predominate in its upper part, among which there are individual thin horizons of titanomagnetite ores. In the stratified series, low concentrations of Cu, Ni and Cr are recorded, which is linked to high alumina content and low magnesia of the parent melt. Higher copper contents, at low nickel concentrations, are established only in sulphide-containing gabbroids and sometimes reach industrial concentrations. Stratified and trachytoidal textures are characteristics of the stratified series, fixing the elements of the primary magmatic stratification. The marginal facies of the Khayrkhan massif has an apparent thickness of about 0.5-1 km and is developed predominantly on its northeastern flank. The marginal facies are characterized by a relatively homogeneous structure with gradual transitions between the varieties. Nevertheless, especially in the mesotypic and leucocratic differences, the elements of gneiss and trachytoids are fixed. The main petrographic varieties are the harmless gabbro-norites with local development of plagiovebsterites and pyroxene anorthosites, which are gradually replaced by amphibole-quartz-bearing gabbro-norites towards the enclosing stratum. The transition between the rocks of the marginal facies and the stratified series is rather gradual and, as a rule, is traced by the development of veins of pegmatoid gabbro-norites and leuco-gabbro-norites. The rocks of the marginal facies have lower Co, Ni, and Cr contents than those of the stratified series, but higher copper grades, which sometimes reach industrial values. Analysis of the patterns of spatial orientation of elements of internal anisotropy of gabbroids (banding, trachytoidity, mineral flattening) allows us to assume the general anticlinal structure of the differentiated series of the array with the southwestern vertex of the axial surface. The northeastern flank is dominated by a fall in the eastern rumbles at angles of 50-70°, and in the southwestern direction, respectively, in the western at angles of 70-90°. The generalized anti-form of the intrusive body is complicated by the development of lower-order kinematic folds and tectonic disturbances of the up-and-over or shear kinematic nature [5].

Prospects of ore content of the Khayrkhan gabbroid massif were previously associated with the development of dispersed chalcopyrite-pyrrhotite mineralization, which reveals an increase in the concentrations of platinoids (up to 0.3 g / t according to scintillation analysis). Mineralogical researches of the richest PGE samples allowed to determine the presence sperrylite, mertiit, osarsit and stibiopalladit [5]. Among the gabbroic blocks outside the main body, industrial gold contents (up to 5 g / t) were also found in the local copper sulfide accumulation zones. These data served as the basis for carrying out prospecting for precious metals that were performed by employees of Tomsk State University with the support of the Australian mining company Elayne Nominees P TY.LTD. In the course of field and laboratory studies, about 200 large-volume (3-7 kg samples) samples from sulfidated varieties of gabbroids of the Khairkhan Massif were selected and analyzed. The obtained results made it possible to establish that elevated concentrations of noble metals are fixed only in the form of local horizons (with a thickness of about 3-5 m), sustained along a strike up to 10-15 km. Such a character of ore deposits corresponds to the concept of "reef", which is used when characterizing many stratified ultramafic-mafic intrusions. In total, four such reefs with a total content of gold, palladium and platinum from 0.03 to 1.6 g / t were found within the Hayrkhan massif (table 1) [5].

The first horizon is confined to the contact of the marginal facies and the stratified series. It occupies

the extreme north-eastern position in the structure of the massif. The maximum concentrations of noble metals (140-430 mg / t), as a rule, are tied to the veins of pegmatoid leucocratic gabbroids, revealing a pronounced gold specialization with an average value (Pd + Pt) / Au of about 0.2.

The second and third horizons are localized within the stratified series of mafites and are associated with melanocratic differences of the gabbro-peridotite type, plagiuverlites and olivine plagiovebsterites. These horizons show increased concentrations of gold and platinoids. Moderate accumulation of precious metals (an average of 90 mg / t) with a PGE / Au ratio of about 0.75 fixed for the second horizon. In the third "reef", the average content of useful components is slightly higher (up to 320 mg / t, and in some samples approaches industrial concentrations to 1600 mg / t) with a more significant role of platinoids (PGE / Au = 0.80). Both these horizons are traced along the entire massif, over a distance of about 10 kilometers. The estimated thickness of these horizons varies from 2 to 10 meters [5].

Table 1. The content of noble metals (ppb) in the ore-bearing horizons of the Khairkhan massif[a] [5].

Metal	Reef 1 (11)[b]			Reef 2 (9)		
	min	max	av	min	max	av
Au	29	353	134	7	90	53
Pd	5	60	23	13	129	33
Pt	5	13	36	5	18	7
Sum	40	432	163	35	234	93
(Pd+Pt)/Au	0,06	0,62	0,22	0,21	4	0,75
Metal	Reef 3 (9)			Reef 4 (6)		
	min	max	av	min	max	av
Au	9	972	178	3	36	14
Pd	5	340	98	13	70	35
Pt	5	296	44	5	24	8
Sum	51	1591	320	28	111	57
(Pd+Pt)/Au	0,29	4,67	0,8	1,1	28	3,07

[a] Analyzes were performed by assay method with ICP-MS termination in the analytical center of Alex Stuart Assayers Kyrgyzstan LTD (Bishkek, Kyrgyzstan).
[b] The number of samples taken from each horizon is indicated in parentheses.

The fourth ore horizon is located in the axial part of the massif among the olivine gabbroids at a considerable distance from the previous ones (up to 1000 meters). It is tracked in fragmentary single samples for a distance of up to 8 km. This reef is characterized by a sharp predominance of platinoids over gold (PGE / Au = 3.0) with a relatively low level of accumulation of about 60 mg / t [5].

The richest noble metals were the first and third reefs. The study of the material composition of the ore minerals of these reefs gave the following results. Pyrite, chalcopyrite and bornite are most common among sulfides. In most cases, their composition is close to stoichiometric, but reveals, nevertheless, a certain discreteness. In particular, the sulfides of the first (predominantly gold-bearing) horizon are characterized by elevated sulfur concentrations that determine the excess of this anion in the calculated formula of minerals. Electrum and native gold are also used as the actual Au mineral phase, and higher (from 3.2 to 6.8% by weight) silver and a constant admixture of platinum (0.02-0.06% by weight) are found in the bornite. This pattern suggests an increased acidity of ore-forming solutions. In the sulfides of the third (gold platinum) horizon, as a rule, a weak but constant sulfur deficit is observed against the background of increased concentrations of mercury and tellurium. The detection of a fairly rare palladium telluride temagamite Pd3HgTe3, completely confirms the general evolution of the ore-bearing

hydrothermal column, where sulfur is the most mobile component [5].

In general, the ore paragenesis of the gold-platinum-bearing reefs of the Khairkhan Massif indicates a significant role for volatile components in the formation of noble metal mineralization at relatively low temperatures, i.e. real participation in their secondary enrichment of hydrothermal solutions. The observed zoning in the deposition of gold and platinoids seems to reflect their mobility at the magmatic and hydrothermal stages of the evolution of the initial basite magma under conditions of variations in the partial pressure of mercury, tellurium, sulfur and oxygen.

Thus, the object studied by us can be regarded as quite promising for noble metal mineralization. Its considerable size, taking into account the continuity of the ore-bearing horizons over considerable strike distances, allows one to assume the industrially significant reserves of platinum and gold. According to its structural-genetic type, the mineralization of the Khairkhan massif corresponds more to the low-sulfide platinum-bearing formation of the JM reef in the Styllurian massif, however its purely copper specialization resembles the Duluth complex in the state of Minnesota [5]. Considering that in most differentiated ultramafic-mafic intrusions, platinum-bearing reefs have an average thickness of about 10-30 cm, and in our case, wider ranges of the stratified gabbroide series were estimated (up to 5-10 m), while further prospecting should allow for much higher concentrations of precious metals in the rocks of this pluton.

Acknowledgements

This work was conducted as a government task of the Ministry of Education and Science of the Russian Federation, Project Number 5.2352.2017/4.6. The examinations of samples were performed on the equipment of Analytic Center of Natural Systems Geochemistry of Tomsk State University.

References

[1] Izokh A E, Polyakov G V, Krivenko A P, Bognibov V I, Bayarbiyeg L 1990 *The Gabbroid Formations of Western Mongolia* (Novosibirsk: Science, Sib. Dep.) p 269

[2] Pavlenko A C, Fedorova M E, Kovalenko V I, Kuzmin M I, Louvsandanzan B, Orlova L P, Pavlenko V C, Filippov L V 1974 Granitoid formations *Tect. of the Mong. Rep.* 210 – 34

[3] Dergunov A B, Louvsandanzan B, Pavlenko V C 1980 *Geology of Western Mongolia* (Moscow: Science) p 195

[4] Izokh A E, Polyakov G V, Anoshin G N, Golovanova N P 1991 Geochemistry of platinum metals, gold and silver in the Nomgon troctolite-anorthosite-gabbro massif (MNR) *Geochemistry* 10 114 – 17

[5] Gertner I F, Tishin P A, Bazhenov R S, Voitenko D N 2003 Prospects for the noble mineralization of the Khayrkhan gabbroid massif (Western Mongolia) *Tomsk State University Journal* 3 223 – 25