FEATURES OF THE COMPOSITION AND THE STRUCTURE OF THE ELOV DEPOSIT NICKELIFEROUS WEATHERING CRUST (THE SEROV GROUP OF DEPOSITS, URALS)

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ABSTRACT. The extremely complex geological structure of the Elov deposit's substrate, the large variety of source rocks that form it, the long period of development of various weathering processes occurring in different geological eras and in different climatic conditions led to the complicated structure of the weathering crust and the variety of decomposition products of source rocks, the vast majority of which have industrial concentrations of useful components. Before the discovering of the Serov group of deposits the nickel-bearing weathering crusts with similar structure were not previously known both in Russia and abroad. The purpose of this work is to investigate the mineral composition, as well as the geochemical features of the Elov deposit's rocks (Urals). The types of rocks of the Elov deposit were identified and studied, it may allow to find more search signs to the nickel and the minerals associated with it. The lateritic nickel ore deposits are widely distributed throughout the globe, so they are becoming increasingly important as a potential source of nickel.

Keywords: nickel-bearing weathering crust, Elov deposit, Urals

ОСОБЕНОСТИ НА СЪСТАВА И СТРУКТУРАТА НА СЪДЪРЖАЩАТА НИКЕЛ ИЗВЕТРЕНА КОРА НА ЕЛОВСКОТО НАХОДИЩЕ ОТ ГРУПАТА СЕРОВ (УРАЛ)

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РЕЗЮМЕ. Изключително сложната геоложка структура на субстрата на Еловското находище, голямото разнообразие на изходни скали, които го формират, дългият период на развитие на различни процеси на изветряне, протичащи в различни геоложки епохи и различни климатични условия, са довели до много сложна структура на изветрителната кора и огромно разнообразие от разграждащи се продукти от изходните скали, като по-голямата част от тях съдържат промишлени концентрации на полезни компоненти. Преди откриването на Серовската група от находища, изветрителна кора с подобна структура не е била известна досега както в Русия, така и в чужбина. Целта на тази работа е да се проучи минералният състав, както и геохимичните характеристики на скалите на Еловското находище (Урал). Идентифицирани и изследвани са типовете скали от Еловското находище, което позволява да бъдат открити признаци за наличието на никел и свързаните с него минерали. Латеритните находища на никелова руда са широко разпространени по целия свят, така че те стават все по-важни като потенциален източник на никел.

Ключови думи: никел-съдържаща изветрителна кора, Еловско находище, Урал

Introduction

During the last century, the nickel industry of the Urals was based on numerous supergene oxide–silicate ore deposits, which supplied raw materials to the Yuzhuralnikel and Ufaleinikel metallurgical plants, as well as Rezh and Buruktal mills. At present, new metallurgical plants are under active construction on the basis of the lateritic nickel ores of such type (>70% of the world's nickel reserves) in Australia, New Caledonia, Cuba, Indonesia, Samoa – New Guinea, Brazil, Columbia, Venezuela, and other countries. In terms of mineral composition, and, partially, geological position, the Uralian ores are similar to the Ni–bearing lateritic ores in the Earth's modern tropical belt, but they are not their complete analogues. The majority of the Uralian deposits mainly contain low–grade ores with Ni content of 0.7–1.0%. The wide compositional diversity of their ore and non – ore rock – forming minerals significantly affects the technology of nickel processing. The main Ni – carriers in the ores are Mg–silicates (serpentines, chlorites, and nontronites), with the minor contribution of iron and manganese hydroxides. The Ni content in these minerals is 1–3%, increasing in some chlorite and serpentine species to 7–12% or more. In this work, we have analysed the rock species from the Elov oxide–silicate nickel deposit.

Geology

The Serov group of nickel-cobalt ore deposits is located on the eastern slope of the Northern Urals. The main structural elements of the region are the Tagil megasynclinorium and the Verkhotursk-Verkhisetsk meganticlinorium of the Uralian orogen (Fig. 1). The megasynclinorium is represented by its eastern flank, which occupies the western part of the region, and the meganticlinorium is represented by the western flank, which covers the area which is situated to the east of the first one. The boundary between these structures passes through the Serov-Mauksk submeridional deep fault (Gottman, Pushkarev, 2009).

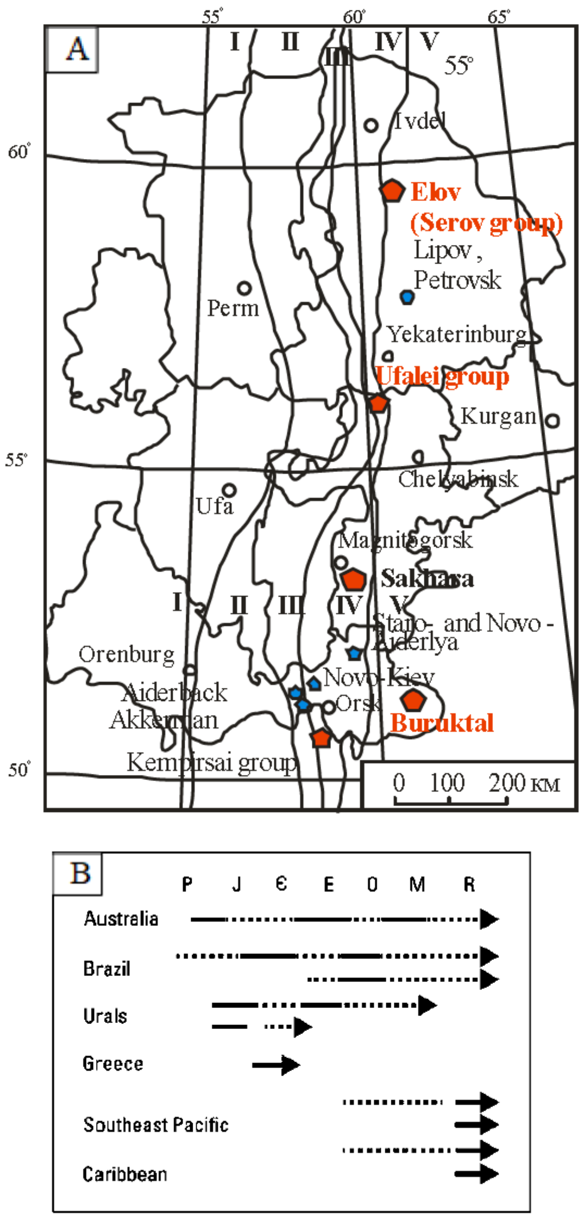

Fig. 1. (A) Main tectonic units of the central and northern Urals with the nickelhydrosilicate ore deposits (after Mikhailov, 2002) and (B) Periods of nickel laterite formation in various provinces (after Marsh et al., 2013)

Tectonic zones: *I*, the East-European platform; *II*, the Fore-Ural megazone; *III*, the Central-Ural megazone; *IV*, the Tagil-Magnitogorsk megazone; *V*, the East-Ural megazone. Main supergene nickel deposits: the Buruktal deposit, the Ufalei group (the Cheremshanka, the Sinara, the Rogozha deposits), the Serov group (the Elov deposit); *P*, Paleozoic; *J*, Jurassic; *Є*, Cretaceous; *E*, Eocene; *O*, Oligocene; *M*, Miocene; *R*, recent

The nickel ores in the Elov deposit were formed as a result of the weathering of the ultramafic rocks of the Kola massif which belongs to the Serov belt (Lazarenkov et al., 2006).

Lateritic weathering

Nickel-bearing ore mineralisation of the Elov deposit (Fig. 2) is confined to the weathering crust of ultramafic rocks of peridotite's formation which all nickel deposits of the Urals and the North Kazakhstan are related with (Bugelskiy et al., 1990; Vershinin, 1993).

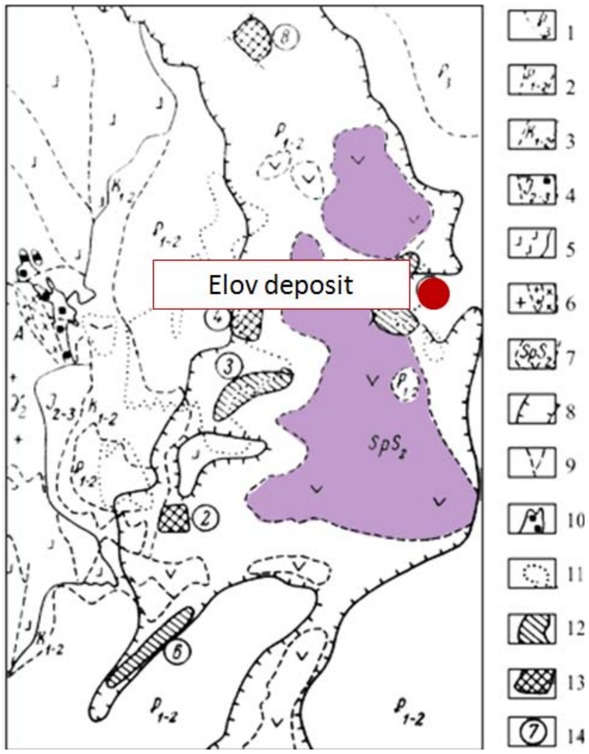

Fig. 2. Schematic geological and technological map of deposits of the Serov group (after Vershinin et al., 1988)

1–4, Meso-Cenozoic deposits of the weathering crust; *5–6*, Paleozoic formations; *7*, day stones of serpentinites; *8*, contours of serpentinites in accordance with magnetic survey and drilling; *9*, zones of tectonic dislocations; *10*, chalcopyrite-magnetite skarns; *11*, nodular-conglomerate sedimentary iron ores in the deposits of the Myssov suite; *12–14*, deposits of supergene nickel ores of various technological types: *12*, ores for alkaline hydrometallurgical process, *13*, ores for blast smelting process; *14*, numbers of deposits. The Serov group of deposits: 7, Elov; 6, Katasmin; 8, Ustey; 2–4, others

The Elov deposit (Fig. 3) contains a large number of minor intrusions in contrast with all other Urals' deposits and for the formation of the weathering crust with equivalent nickel content as in other deposits with similar composition it would be required twice the amount of nickel in the source serpentinites or double expansion of decayed and weathered serpentinites, from which fully leached nickel was redeposited in orebodies (Trescases, 1986).

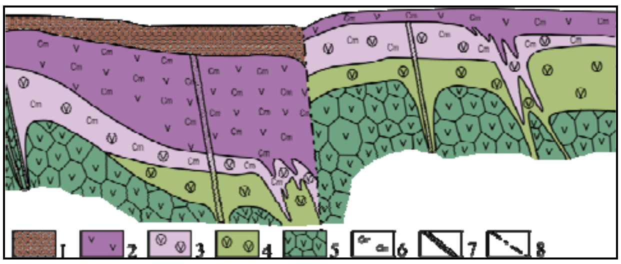

Fig. 3. Geological record of the weathering crust of the Elov deposit (after Berkhin et al., 1970)

1, nodular-conglomerate sedimentary iron ores (K_1); *2*, yellow earth; *3*, nontronited and ocherized serpentinites; *4*, leached serpentinites; *5*, disintegrated serpentinites; *6*, chamosites; *7*, chlorite vein-rock; *8*, fractures

According to calculations of the ratio of minor intrusions' height to the seam height of serpentinites in the central part of the Elov deposit, minor intrusions estimated for 40% of the total rocks thickness, sometimes in some small areas the volume of vein-shaped bodies exceeds the volume of the serpentinites (Mikhailov, 1999; 2002).

Processing

Currently, three different processes (Fig. 4) are used to extract the nickel and cobalt elements from the mined rocks. The Caron process and high-pressure-acid leaching (HPAL) are mainly used for the oxide ore subtypes. For the nickel clay deposits, the HPAL method is also used with priority, whereas for the serpentine subtypes, a pure melting method is preferred. Ongoing research is developing new extraction methods, such as the Dni-Hydrometallurgy process developed by DirectNickel, which can also process the entire laterite profile without prior separation. However, because of the complexity needed to handle and process the nickel-cobalt laterites, much research has focused on ore delineation and mineralogical identification for distinguishing rocks. Thus, it is important to characterise the mineralogy of the Elov deposit in more detail.

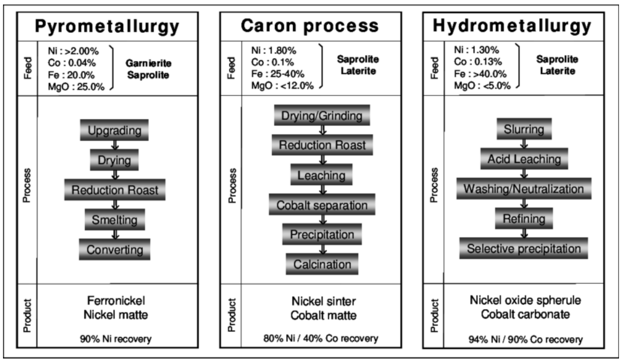

Fig. 4. Main processes for the extraction of nickel out of lateritic rocks

Materials and Methods

Samples

Nine samples were used for the investigation, which were collected during an excursion led by Prof. Dr. Irina Talovina (Saint Petersburg Mining University) and Prof. Dr. Gerhard Heide (TU Bergakademie Freiberg) in the active open pit Elov near the town of Serov in September 2014. The samples are crude ore as well as country rock that occur within the open pit area. The samples are listed in Table 1.

Analytical Methods

The mineralogical composition of the samples was determined by using x-ray diffraction phase analysis. All samples were prepared as powder preparations. The rocks were crushed with a hammer down to a grain size < 400 µm. The bulk samples were subsequently divided using quarter cross. Further crushing was done using the ball mill XRD-Mill McCrone with ZrO_2-grinding bodies. Technical ethanol (96%) was used for cooling and to guarantee careful grinding. After drying, the samples were homogenised by means of an Ardenne vibrator and finally sieved with a 200 µm sieve into an aluminum cuvette using the side-loading procedure. The measurements were executed with URD 6 (Mineralogical Laboratory, TU Bergakademie Freiberg) with Co-radiation.

Table 1. *The investigated samples with nickel content, %.*

Sample	Name	Ni
SV 02	Porphyritic serpentinite	0.117
SV 04	Chromite ore	0.056
SV 06	Talc-chlorite-schist	0.542
SV 07	Limonite ore	1.160
SV 08	Gangue rock	0.199
SV 09	Contact-zone of SV08	0.163
SV 10-1	Silicate nickel ore	0.101
SV 10-2	Silicate nickel ore	0.979
SV 11	Oxide nickel ore	1.030

To investigate the swelling capable minerals which show mainly wide reflexes in the 14 Å area, texture preparations were produced in the traditional way. The selected samples were first measured in an air-dried state, afterwards they were saturated in ethylene glycol vapour and then measured again. The ethylene glycol accumulates in the interlayers of the minerals and causes a widening of the structure, thereby increases the layer distance. After the second measurement, all texture preparations were annealed at 400°C and measured again. The last measurement was executed after an annealing process at 550°C.

Thermal analyses were carried out in the Mineralogical Laboratory of the TU Bergakademie Freiberg (Dipl.-Chem. Margitta Hengst). All measurements were realized by means of the STA 409 PC, and a heating rate of 10 Kelvin per minute, up to a maximum temperature of 1200°C. Purified air was used as a carrier gas for all analyses. The reference material for the DTA analyses was corundum (Földvari, 2011).

The observations on the scanning electron microscope (SEM) were mainly examined on polished thin sections of the solid rocks. Individual measurements were also carried out on strewn slides. For the investigations it was possible to use the CarryScope JCM-5700 from the "Terra Mineralia Freiberg" museum. This SEM is equipped with a Bruker EDX (133eV). The focus of this analytical method was the determination of the spinel group minerals. Further questions arose with regard to the distribution of the various valuable elements inside the rock units, primarily nickel. As far as possible, this method allowed the investigation of the local coupling of nickel to the various minerals.

Results

The chemical analyses show a significant accumulation of nickel in various rocks of the open pit. Most of the silicate dominated areas of the deposit contain higher nickel concentrations, however, they are not high enough to reach economic relevance. The rocks display nickel contents between 0.101% and 0.542%. An exception is the major amount of silicate nickel ore (SV 10-2), which at 0.979% shows significantly increased nickel contents of economic importance. It is note-worthy that only the unaltered areas of the silicate nickel ore have significantly elevated contents, while the secondary silicified zone has only a very low nickel content of 0.101%. Since the biggest difference is found in the mineral composition, in this case the increased content of serpentine and especially smectite in the non-silicified areas, the nickel must be linked to exactly these minerals. It can be assumed that these are typical nickel-containing nontronites (Brindley et al., 1973; Brindley, 1984a, b).

The highest nickel contents were detected in the oxidic type nickel ore of SV 11 (1.03%) and in the limonite ore of SV 07 (1.16%). Thus, these areas are most enriched when considering the absolute contents. As far as the limonite ore is concerned, it can be assumed that the nickel is primarily coupled to nickel-rich goethite and very occasionally to nickel sulphides. The rock contains neither smectite nor talc, and the serpentine branch veins (apophysis) in which EDX analyses did not show any major nickel content, are the result of later secondary formation. According to the elevated position of the dehydroxilation peak, the thermal analyses of goethite indicate a significant foreign metal substitution, further substantiating the thesis of nickel-rich goethite (Talovina et al., 2008; 2010; 2011; 2012; Talovina, 2012a; 2012b). Although nickel sulphides have been detected in the limonite ore, their absolute contents are negligible compared to the substitutional placement in the goethite structure. This is corroborated by the missing peaks in the powder diffraction pattern as well as by the low sulphur content of the sample. It merely amounts to 0.10% sulphur content compared to the 1.16% nickel content. In the oxidic type nickel ore (SV 11), the nickel carrier cannot be reliably determined. However, enrichment in the silicate components seems to be plausible, especially in chlorite and smectite as well as in goethite, which also has increased *d* values. Also in this particular rock the serpentines showed no relevant nickel content throughout the EDX measurements.

Conclusion

The Serov group of deposits is one of the sedimentary-infiltration formations. The Orsk-Khalilovsk, Aydyrlinsk and other deposits, except the Elov deposit, belong to this kind of formations in the Urals. In this type a significant role belongs to the nickel-containing ore-forming ferruginous chlorite, i.e. shamosite $(Fe_5Al)(AlSi_3O_{10})(OH)_8$. The deposits of this type had experienced a rather complex history of formation, including the stage of epigenesis (destruction, transportation and deposition with the formation of ferrous sedimentary rocks) in addition to the lateritogenesis stage (cf. Yudovich et al., 2011).

The vertical zonal profile in the nickel weathering crust of the Elov deposit is observed (from the bottom up): serpentinised ultramafics (substrate)–serpentinite zone–nontronite zone–oxide-iron zone. Separately, it is worth noting the shamosite zone, which belongs to the converted part of the weathering crust of the Elov deposit, has a limited distribution and replaces serpentinite, nontronite and oxide-iron zones partially or completely.

The research displays a very diverse mineralogy in the rocks of the Elov deposit. It was shown that different types of rocks from variously weathered areas of the deposit have relevant nickel contents. Due to the different mineralogy of the nickel-bearing minerals between laterite and saprolite, both a selective mining and a selective processing of the individual types of ore should be considered.

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