

UDC 622.7, 553.4

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## SUPERGENE OXIDE-SILICATE NICKEL DEPOSITS: MINERAL-GEOCHEMICAL COMPOSITION AND PECULIARITIES OF PROCESSING\*

### Introduction

Nickel deposits in the world are represented by two main ore types: supergene (oxide-silicate) nickel ores of weathering crust and endogenous sulfide Cu-Ni deposits. Oxide-silicate nickel ores account for more than 80% of nickel reserves in the world containing at the average 1.1–2.6% Ni. Their contribution increased from 29.4% in 1961 to 55% in 1987 in the nickel production abroad, and this trend is retained at present. Based on such deposits, new metallurgical plants are being constructed and put into operation in New Caledonia, Indonesia, Australia, Brazil, Columbia, Venezuela, and other countries [1].

In Russia, the main nickel deposits are represented by the complex sulfide copper-nickel ores of the Norilsk and Pechenga groups with high content of platinum group elements, gold, silver and other elements. Unfortunately, these highly profitable ores in Russia decrease [2].

Oxide-silicate ore deposits contain approximately only 10% of nickel reserves, but they are situated in more favorable mining areas of the Ural region with high-developed infrastructure. They serve as a raw material base for the Ufaleinikel and Yuzhuralnikel metallurgical enterprises, as well as the Rezh and Buruktal plants.

In recent years, the production of nickel in the Urals has been gradually reduced. The reason for this is primarily the depletion of high-grade ore deposits and the use of old-fashioned technologies [2, 3]. According to recent data, the amount of nickel produced by "Ufaleynikel" is only 5.4% of the total nickel output in the Russian Federation. Originally, the ore from a nearby deposit (Cheremschan) was used, while now the ore is transported for about 700 km from the Elov deposit by train to the plant. The average nickel content is about 0.7–1.0%, hence lower than the average grade of nickel ore mined worldwide. Except nickel, the plant formerly produced a number of byproducts such as cobalt. In addition, our investigations of nickel ores in the Buruktal, Sakhara, Serov, Ufalei, and Elizavet deposits of the Ural province demonstrated that contents of PGM, Au, and Ag may reach as much as 0.00n–0.n g/t [4–7]. All these elements are essentially associated components of the nickel ores.

Presently, the oxide and hydrosilicate nickel ore with an initial humidity of 23–27% is first dried to about 14% humidity and then molten in a pyro metallurgical process in a shaft

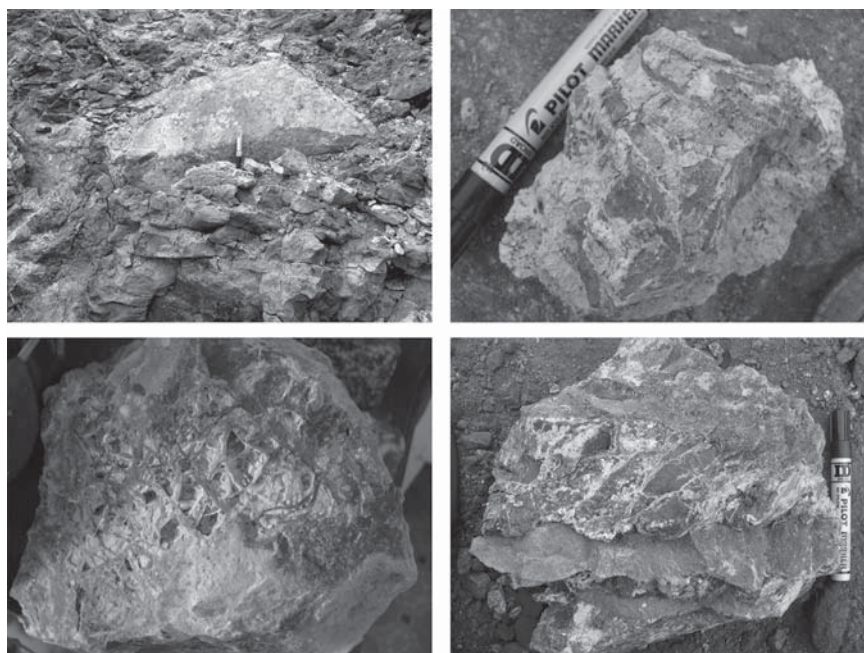
*In Russia oxide-silicate supergene nickel deposits require a revision of technological schemes of extraction of useful components in order to improve profitability and the integrated use of the objects of the mineral resource base in the developed mining province of the Ural region. The most important industrial mineral of supergene nickel ore is so-called garnierite. The X-ray and other data suggest that this substance includes several mineral phases, mostly silicates and hydrosilicates of nickel and magnesium. We studied this substance in epy ores of the Cheremshan, Sinar, Elov, Sakhara, and Buruktal deposits based on chemical, thermal, and X-ray phase analysis data. The analysis of the mineralogical and geochemical composition of the ores also shows that these ores meet the criteria of selective disintegration. The different characteristics of the rocks and ores in supergene deposits call for a selective processing of the various ore containing constituents to make metal production efficient. In particular, the wet and sticky laterites should be separated from solid serpentinites, allowing a separate processing of both. Since the transition zone, containing both materials may be rather wide, an efficient separation technology shall be applied. Then the serpentinite rocks can be further processed separately from the clayey laterites. Analysis of the obtained results shows that the use of vertical roller mill saves 25% of the collector or allows achieving the same recovery in a third of time at the same reagent costs.*

**Key words:** Ni production, Ni consumption, alternative technologies, leaching, the Urals, economic challenges of regions  
**DOI:** 10.17580/em.2017.01.06

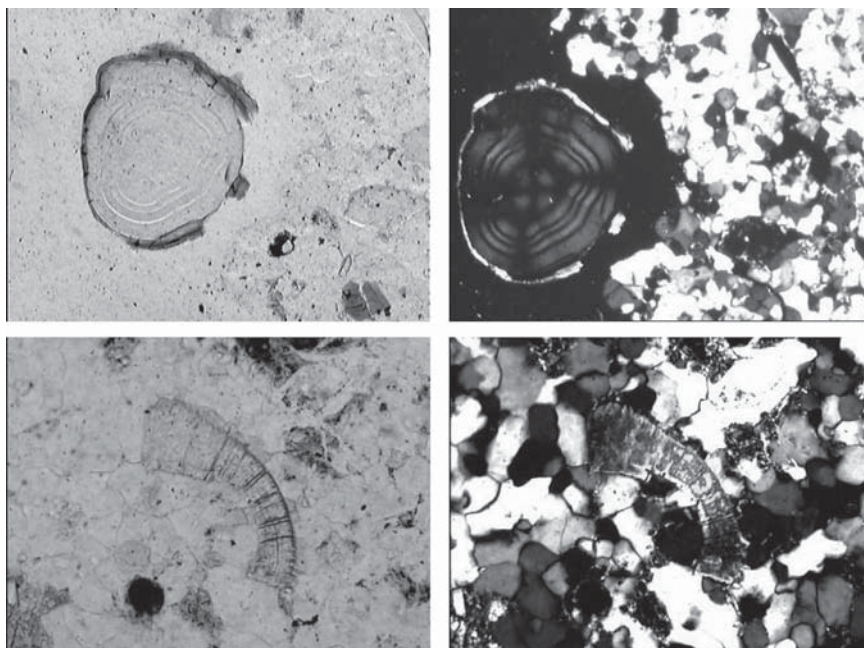
kiln using coke for heating, without any pre-concentration. The produced nickel mattes are further processed in converters while the granulated slag is dumped and the exhaust fumes are released to the atmosphere after some dedusting. The technology is pretty much the same, which was introduced in the early 1930th, when the plant was built.

A challenge of nowadays is not only in dealing with the interventions in a fragile ecosystem, sometimes in densely populated areas, but especially in the absence of efficient mobile technology that can be adapted quickly and individually to changing conditions of small-scale complex nickel deposits in order to enable a first enrichment near the mine. The basis for the development of new technology is the exact knowledge of the chemical bonding of the valuable elements of the enriched mineral phases. To develop alternative extraction methods, such as the leaching, as well as for issues of enrichment, it is necessary to know the mineralogical phase composition and genesis of the ore.

\*Research is executed by a grant from the Russian Science Foundation (project No. 15-17-00017).



**Fig. 1. Ores of the nontronite zone (above) and the zone of leached serpentinites (below) of the Ural deposits**



**Fig. 2. Spherulite aggregates of nepouite 2Or and accordion-like aggregates of pecoraite 2Mc, in the Cheremshan deposit (left – without analyzer, right – with analyzer)**

#### Mineral-geochemical composition of the ore

The deposits are well studied by Russian geologists, including scientists from the St. Petersburg Mining University. A profile of a typical deposit represents three weathered zones, from top to bottom: 1) iron-oxide zone (goethite ores) – 15 m; 2) nontronite zone (nontronite, chamosite ores) – 50 m; 3) serpentinite zone (chrysotile-lizardite and nepouite-chrysotile-lizardite ores) – 30 m. Most of the Ni is contained in the chamosite zone of the lateritic layers. This

zone may be some 50 m thick in certain places. The material is wet and sticky. Primary enrichment and separation so far requires a rather difficult technological process.

Despite the clayey laterite contains the highest concentration of nickel, the underlying serpentinites still contain amounts which are not negligible. Contrary to the clayey laterites, weathering crusts on the surface of the serpentinites were formed. Here the majority of the nickel ore results from veins and veinlets guiding the hydrothermal flows (**Fig. 1**).

The most important industrial mineral of supergene nickel ore is so-called garnierite (**Fig. 1, 2**). At present, the term “garnierite” is omitted from mineral handbooks, because the X-ray and other data suggest that this substance includes several mineral phases, mostly silicates and hydrosilicates of nickel and magnesium [8]. We studied this substance in epy ores of the Cheremshan, Sinar, Elov, Sakhara, and Buruktal deposits based on chemical, thermal, and X-ray phase analysis data. Chemical analyses were carried out by the atomic absorption method in the Chemical Laboratory of the St. Petersburg State Mining Institute (O. L. Galankina, analyst); thermal analyses, with a Netzsch STA 449C device in the Thermal Laboratory of the St. Petersburg State Mining Institute (V. L. Ugolkov, analyst); and X-ray phase analyses, with a Giegerflex-D/max X-ray powder diffractometer in the laboratory of the Mekhanobr-Analit Joint-Stock Co. (M. A. Yagovkina, analyst). Microprobe analyses were performed on a JEOL JSM scanning electron microscope equipped with EDS Noran Explorer at the Freiberg Mining Academy, (U. Kempe, analyst). The X-ray data were deciphered based on the International Centre for Diffraction Data (ICPDF) classification.

The obtained data are shown in **Fig. 3**. In the Si–Mg–(Fe+Ni) diagram, data points of the Uralian garnierites make up two paragenetic mineral associations: hydrothermal association (pecoraite 2Mc, + chrysotile 2Mc, и 2Or, + clinocllore //B + talc + willemseite + phlogopite + quartz) and superimposed exogenous association (nepouite + lizardite 1T + sepiolite + palygorskite + nontronite + saponite + smectites + vermiculite + quartz).

Thus, we should mention that the obtained results have an important mineral–technological aspect. As compared to the low-temperature exogenous mineral association of nickel deposits, hydrothermal minerals are characterized by higher melting temperatures, other temperatures of phase transitions, and higher values of heat capacity. All these features surely influence the process of ore preparation and, particu-

larly, the process of melting. They require a higher power consumption and, consequently, higher financial expenditure. The relationship between the mineralogical and technological characteristics of ores with the need for mechanoactivation and selective comminution is shown in [9–11].

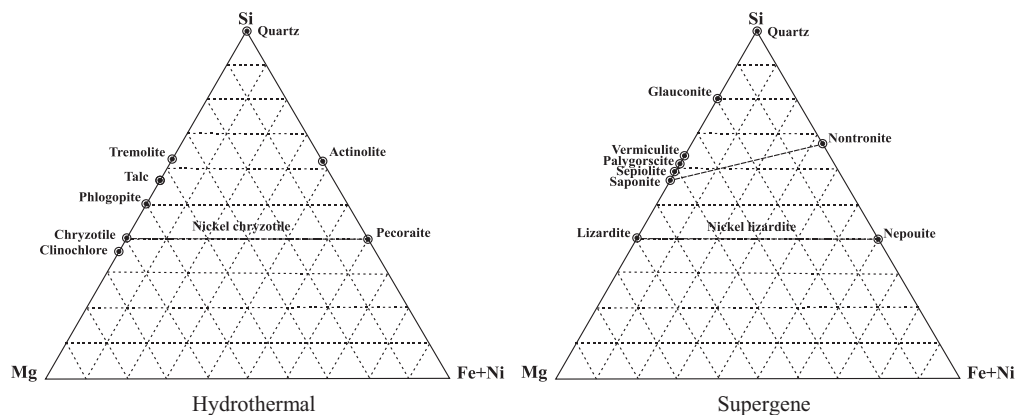
The analysis of the mineralogical and geochemical composition of the ores also shows that these ores meet the criteria of selective disintegration [12–15]. The different characteristics of the rocks and ores in supergene deposits call for a selective processing of the various ore containing constituents to make metal production efficient. In particular, the wet and sticky laterites should be separated from solid serpentinites, allowing a separate processing of both. Since the transition zone, containing both materials may be rather wide, an efficient separation technology shall be applied. Then these serpentinite rocks can be further processed separately from the clayey laterites.

A promising way to process the laterites in an efficient way could be leaching, either pressure leaching or atmospheric heap leaching in combination with solvent extraction/electro winning technology. For processing the serpentinites the nickel content in the rock itself needs to be investigated. Then selective comminution might be recommendable producing a high grade concentrate in a certain fraction. A number of the above mentioned questions were already investigated at the TU Bergakademie Freiberg, Germany with promising results [16]. To grind the ore, a ball mill and a Loesche type vertical roller mill (VRM) were used [17]. The moisture of the material loaded into the Loesche mill was 15–18%, and the material was dried directly in the VRM. The material with initial fineness + 25 + 0 mm was ground to flotation sizes, namely to 0.0074 + 0 mm. Flotation was carried out in pneumo-mechanical machines. As a collector, a cation collector (KIU) was used. Consumption of the collector varied from 450 to 600 g/t. Results on comparative flotation tests in Ni processing are shown in Fig. 4.

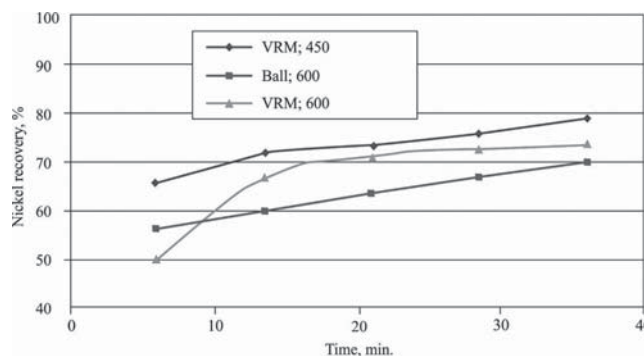
Analysis of the obtained results shows that the use of VRM saves 25% of the collector or allows achieving the same recovery in a third of time at the same reagent costs. Now the laboratory experiments will have to be verified with the ores from the Urals deposits and transferred into industrial scale.

**Conclusion**

Creation, improvement and introduction of modern technologies of processing of oxide-silicate nickel ores and their integrated use with the extraction of associated components, including precious metals, can solve social and economic problems of the industry and the region. This requires joint work of experts from various fields, such as mineralogy, geology, mineral processing in order to study the mineral composition of ores and development of alternative technologies for their processing. The analysis of the mineralogical



**Fig. 3. Paragenetic associations of hydrothermal and exogenous mineral phases in garnierites of the Ural province (in molar ratios)**



**Fig. 4. Dependence of nickel extraction on flotation time**

and geochemical composition of supergene nickel ores shows that the ores meet the criteria for selective disintegration, and the different structural and physical characteristics of oxide and silicate ore require their selective processing and pre-concentration. In particular, nontronitic and shamosite clays must be separated from fragments of leached serpentinites for further separate processing of them. For the enrichment of leached serpentinites, selective comminution and grinding can be recommended to produce a high output of nickel concentrate in a certain fraction followed by flotation. Some technologies, that are more efficient, are available at least in laboratory scale to make nickel production profitable in the medium term even at the present low price levels and with low-grade ore deposits.

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UDC 622.765.4

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## A REVISIT OF SELECTION THE EFFICIENCY CRITERION FOR FLOTATION REAGENTS OF FATTY ACIDS CLASS\*

### Introduction

The collective ability and selective action of collector agents is believed to depend mainly on their sorption characteristics at the solid – liquid interface. A number of studies have demonstrated that the collective ability of reagents (carboxylic acids, amines) can be influenced significantly by their property of reducing the surface tension at the gas-liquid interface. The correlation between the surface pressure in the carboxylic acid film located on the free surface of the solution and the floatability of mineral was established empirically [1–4]. At the same time, this “surface pressure – floatability” relationship fails for long-chain saturated carboxylic acids. Quast indicated that the value of surface pressure of the reagent film does not always characterize the collective ability of a carboxylic acid. For example, the pH range of the increased recovery of hematite by tetradecanoic acid does not coincide with the pH region of high surface pressure. On that ground, the author assumed that the surface properties of this acid do not contribute to the flotation mechanism [3].

*The collective ability of desorbed species (DS species) of saturated carboxylic acids is reviewed. DS species of a reagent denote the forms capable of moving from the mineral surface to the bubble, i.e., to the gas-liquid interface, at the moment of breakout of the interlayer separating these interconnected objects. Experiments on fluorite ore in the presence of mixed cover, including physical and chemical sorption forms, and cover containing only chemical form are performed. As is shown, the removal of physical sorption form decreases recovery of fluorite in concentrate. It was determined, that physical sorption form of carboxylic acid provides specific collective function. The spreading rate of carboxylic acids on water surface is determined at pH 7 and 10. The spreading rate of carboxylic acids is comparable with flotation parameters of fluorite ore with mentioned collectors. The sequence of increasing the spreading rate of middle- and long chain carboxylic acids corresponds with the sequence of increasing fluorite recovery in foam product. A criterion for estimating the collective capacity of carboxylic acids is proposed. Advisability of its application for selection flotation reagent with required collective ability is estimated. Values of forces that influence the liquid in the interlayer at the side of the spreading film of the reagent DS species and the water flow rate from the interlayer are evaluated.*

**Key words:** flotation, criterion for selecting collector agent, saturated carboxylic acids, surface pressure  
**DOI:** 10.17580/em.2017.01.07

\* This study was financed by RSF grant No. 15-17-10017.