INTRODUCTION

Transpolar copper—nickel sulfide ores are the main source of platinum group metals in the country. As estimated by experts, precious metals account for roughly 50% of the cost of the constituents of these ores [1].

It has been proved that in Noril’sk ores platinoids occur in two basically different states. One (mineral form) represents the typical compounds of platinum metals that form in the ores individual mineral phases. The most important among them are intermetallic compounds, tellurides, bismuthides, arsenides, and sulfides. The other state (scattered form) represents solid solutions of platinoids in the main ore minerals, namely, iron and nickel sulfides (pyrrhotite and pentlandite).

The usefulness of studies to reduce loss of noble metals by magnetic methods will become clear if we remember that Noril’sk ores, depending on the ore type, are composed as much as half of pyrrhotite magnetized to varying degrees, and that ferroplatinum, a mineral form of platinum, is also markedly magnetized. Ore concentration rejects account for as much as 80% of the noble metal loss. Therefore, we studied impregnation ore rejects from the Noril’sk ore concentration plant.

No information was found in the open literature on the application of magnetic methods for reconcentration of Noril’sk ore rejects.

Sibsvetmetniiproekt offered us an opportunity to familiarize with their report on a work that included, among other methods, traditional magnetic separation of rejects of the Noril’sk plant [2].

PROPERTIES AND MINERALOGICAL COMPOSITION OF REJECTS

A representative weight (1 kg) of the rejects was graded on a vibratory sieve to determine the size composition. The major part of the study was done on two fractions: −0.05 mm (23.3%) and −0.074 to +0.05 mm (28.1%).

Impregnation ore rejects of the Noril’sk concentration plant is comprised almost 90% of nonore minerals represented by biotite, pyroxenes, feldspars, quartz, and chlorite. Nearly 5-7% is comprised of pyrrhotite and 3-5% of magnetite (ilmenite and titanomagnete). Chalcopyrite and pentlandite comprise tenths of one per cent.

Rejects were studied earlier as well. The sample studied by us was similar in material composition to the one studied before. According to the previous data [2], reject minerals (more than 40) occur in amounts ranging from isolated grains to tenths of one per cent; secondary minerals are cubanite, bornite, millerite, and heazlewoodite; rare minerals are platinum group ones.

Platinum group minerals occur as free grains and as concretions with pyrrhotite and nonore minerals (pyroxenes, biotite, etc.). The mineral ferroplatinum generally occurs, especially in magnetic fractions, as free grains. It has been found that large amounts of platinum group metals are lost with barren rocks essentially at the expense of biotite. Based on
TABLE 1. Magnetic Properties of Rejects

<table>
<thead>
<tr>
<th>Size</th>
<th>$J_s$, G·cm(^{-3})/g</th>
<th>$J_{rs}$, G·cm(^{-3})/g</th>
<th>$H$, kOe</th>
<th>Content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction—0.05</td>
<td>2.8/2.76</td>
<td>0.373</td>
<td>217.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Fraction+0.05</td>
<td>2.1/2.04</td>
<td>0.233</td>
<td>144.8</td>
<td>0.15</td>
</tr>
</tbody>
</table>

extensive mineralogical studies of reject samples it has been concluded that various modifications of pyrhotite are the main carriers of platinoids.

The -0.05 mm rejects studied by us contained 4.0% pyrrhotite, 1.0% pentlandite, 0.3% chalcopyrite, 3.8% magnetite, and 90.9% nonore minerals. The content of nonferrous metals was low: Ni 0.14%, Cu 0.14, Co 0.01, and S 2.91%. The platinum metals together comprised on an average 1.5 g/ton in the rejects and 2 g/ton in the studied size fractions.

Two series of experiments were performed with fresh flotation pulps (slimes and dusts) of impregnation ore rejects from the Noril’sk ore concentration plant, and the pulp was submitted to wet-separation without pregrading.

In mineralogical characteristics and content of precious constituents the rejects were a difficultly enrichible product.

APPARATUS AND MEASUREMENT TECHNIQUE

The magnetic properties of the impregnation ore rejects were studied on two setups: an automatic vibratory magnetometer and a magnetic balance.

The vibratory magnetometer was hooked to a Iskra-1030 computer. The software enabled us to measure the relation $M = f(H)$, i.e., the hysteresis loop (saturation magnetization $J_s$, residual magnetization $J_{rs}$, coercive force $H_c$), as well as the relation $M = f(T)$, i.e., the temperature dependence of magnetization.

The principal magnetization curves for the samples and saturation magnetization $J_s$ were measured on the magnetic balance by the ponderomotor technique.

Traditional magnetic separation of the samples in weak magnetic fields of up to 3 kOe was effected on a series-produced 25T laboratory analyzer. Polygradient magnetic separation on a versatile laboratory separator-cum-analyzer developed by the Department of Rock Magnetism made it possible to work in fields of up to 15 kOe.

MAGNETIC PROPERTIES OF IMPREGNATION ORE REJECTS

A mineralogical analysis showed that the impregnation ore rejects contained two magnetic minerals, viz., magnetite and pyrrhotite, whose concentrations varied with size fractions. In the -0.05 mm fraction they were equal, but in the larger +0.05 mm fraction pyrrhotite dominated. Let us bear in mind that saturation magnetization of magnetite is ~90 G·cm\(^{-3}\)/g and that of pyrrhotites varies from 0.5-5 G·cm\(^{-3}\)/g for the hexagonal and up to ~15 G·cm\(^{-3}\)/g for the monoclinic modifications. Thus, the magnetic properties of the rejects are a superposition of those of magnetite and pyrrhotite, magnetite making the major contribution to their magnetization. The magnetic properties of the rejects are listed in Table 1.

Saturation magnetization was measured by various techniques: on the magnetic balance at $H = 14$ kOe (in the numerator); on the vibratory magnetometer at $H = 11$ kOe (in the denominator).

The hysteresis loop of the -0.05 mm reject samples is illustrated in Fig. 1a. From the course of the curve $J = f(H)$ it will be seen that saturation is virtually complete; the maximum change in magnetization occurs in fields of up to 3 kOe, and its major growth occurs at $H = 1$ kOe.

The temperature dependence of magnetization of the impregnation ore rejects is illustrated in Fig. 1b. Its analysis confirms that the magnetic "part" of the rejects consists of two magnetic minerals, namely, pyrrhotite, as evident from a small inflexion on the curve at $T = 320^\circ$C, and magnetite with a Curie point of 580°C.

Also, let us point out that on the $J = f(T)$ curves there is practically no temperature-dependent magnetic hysteresis, i.e., there is no irreversible change in magnetization $J$ of the ferromagnetic sample lying in a constant magnetic field, during the cyclic temperature change (difference in the course of the $J = f(T)$ heating and cooling curves). This fact suggests that attempts to raise magnetization of the rejects just by heating will not be promising.