Critical processes in the formation of contact-style PGE-Ni-Cu mineralization: Evidence from the Gabbro-10 intrusion as an additional intrusive phase of the Paleoproterozoic Monchegorsk Complex

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Summary Several studies on the Monchegorsk Complex suggest that the gravitational accumulation of sulfide droplets enriched in platinum group elements (PGE) near the bottom of the magma chamber under the condition of preliminary heating of the host rocks by early intrusive phases is a key process in the formation of contact-style PGE-copper-nickel mineralization. Using the example of Gabbro-10 intrusion, which is a late low-volume magmatic phase of the Monchegorsk Complex, we aim to demonstrate the importance of magma enrichment with sulfides occurring at depth in intermediate magma chambers. Moreover, this work substantiates the PGE prospectivity of the Gabbro-10 intrusion and its prospects for scientific drilling.

1. Introduction and background to current research

As a result of our previous studies of outcrops and drill holes on a drill section in the western part of the Gabbro-10 intrusion (Fig. 1), it was possible to establish the following general features of its geological structure and ore mineralization. The Gabbro-10 intrusion is located near the southern contact of the Nyud-Poaz intrusion of the Paleoproterozoic Monchegorsk Complex (2.5 Ga) and represents a flattened subhorizontal metagabbro lens hosted by Archean diorites. The metagabbros are covered with metadiorites separating these rocks from the melanorites of the Nyud-Poaz intrusion. The profile of the Gabbro-10 massif can be subdivided into two zones: (1) marginal zone and (2) gabbro zone. The marginal zone, up to 10 m thick, is composed of fine- to medium-grained schistose metagabbro, geochemically similar to mesocratic gabbro-norites (Groshev et al., 2018a) according to classification (Dubrovsky, 2002). The gabbro zone consists of coarse- to medium-grained metagabbro, often characterized by taxitic texture due to the alternation of rocks with different grain sizes. The thickness of the zone is 30–40 m, increasing towards the east reaching up to 80 m. The geochemical composition of the metagabbro corresponds to quartz mesoleucocratic gabbro-norite. The metagabbro contains xenoliths up to 10 m × 15 m in size. In terms of structural and textural features as well as geochemical composition, most of the xenoliths correspond to melanorite from the Nyud-Poaz intrusion and its endocontact zone (Groshev et al., 2018a). The metagabbro overlaps with the so-called metadiorite, at the base of which a magnetite layer of 1–2 m thickness is present. It is believed that the metagabbro and the metadiorite represent differentiates of the same intrusion. The U-Pb isotope age of the metagabbro is 2497 ± 9 Ma (unpublished data), whereas the age of the metadiorite is 2498 ± 6 Ma (Groshev et al., 2018b), which is within error and coincides with an isotope age of 2504 ± 2 Ma for the Nyud-Poaz intrusion (Amelin et al., 1995). Despite the indistinguishability of isotope ages at a given accuracy, the Gabbro-10 intrusion is clearly a late differentiated magmatic phase of the Monchegorsk Complex.

The PGE-Cu-Ni mineralization of the Gabbro-10 intrusion is associated with unevenly distributed and nested areas of disseminated sulfide (Groshev and Pripachkin, 2018). The dissemination is mainly confined to the marginal zone, but often spreads into the metagabbro

and diorites of the basement. The sulfide content varies from single grains to 10 vol. %. The Pd concentration in the schistose metagabbro of the marginal zone is 0.58 ppm (drill hole 1808), whereas the metagabbro contains 1.78 ppm (sample G181-1 from the outcrop). The basement diorites show up to 2.28 ppm Pd (drill hole 1809). The Ni content in only a few samples of schistose metagabbro and basement diorites exceeds 0.1 wt. % with a relatively high Cu / Ni ratio. It is worth noting that according to the results of historic drilling for nickel carried out by S.M. Rutshtein and colleagues (1964) in the southwestern and eastern parts of the massif, there are two copper-nickel “ore stocks” (Fig. 1) confined to the bottom of the Gabbro-10 intrusion. The nickel concentration of these ore stocks varies from 0.2 to 0.9 wt. %, reaching 1.3 wt. % at most. Since these “ore stocks” were not drilled during PGE exploration in the Monchegorsk Complex, the concentration of precious metals remains unknown.

Figure 3. Schematic geological map (a) and simplified geological sections of the Gabbro-10 intrusion (b) and the Upper Nyud block (c) (Groshev and Pripachkin, 2018). 1 - metagabbrodolerite; 2 - tectonic zone; 3 - metadiorite (a), alternation of metadiorite, basement diorite and magnetite rocks (6); 4 - magnetite rock; 5 - Gabbro-10 intrusion (a - metagabbro, 6 - schistose metagabbro); 6 - Vurechuaivench massif (a - metagabbro, 6 - schistose metagabbro); the Nyud-Poaz intrusion and the Upper Nyud block: 7 - critical horizon, 8 - norite (a), olivine norite (6), melanocratic norite (b), porphyritic melanorite (r); 9 - basement diorite; 10 - sulfide dissemination; 11 - 10th anomaly of electrical conductivity of the Monchegorsk ore region; 12 - approximate contours of copper-nickel ore stocks; 13 - faults; 14 - drill holes (a - assayed for PGE, 6 - studied by the authors, b - assayed only for base metals)

2. Research questions at hand

The confinement of the PGE-Cu-Ni mineralization at the bottom of the Gabbro-10 intrusion and its migration into the basement rocks by tens of meters (Fig. 2) indicate the critical role of gravitational sulfide drainage according to the mechanism described in Karykowski et al. (2018). A favorable factor for sulfide drainage in the Gabbro-10 intrusion is the thermal effect of the early magmatic phase represented by the larger Nyud-Poaz intrusion shortly before the emplacement of the Gabbro-10 intrusion. However, it could be assumed that one of the key roles or even the main role in the formation of the PGE-Cu-Ni mineralization of the Gabbro-10 intrusion is the enrichment of the magmatic crystal mush with sulfides and PGE in an

intermediate magma chamber at depth. This assumption is supported by the numerous small vein bodies of quartz gabbronorites in the South Sopcha intrusion and the Moroshkovoye Ozero area located nearby (Pripachkin et al., 2016). Veins of quartz gabbronorites contain sulfide (3%), magnetite (3%) and nests of disseminated sulfide enriched in PGE reaching 6–8 ppm. It is highly probable that these veins are co-magmatic with the Gabbro-10 intrusion, which can be proved by high-precision isotope dating. An indirect confirmation of the enrichment of magmatic mush with metals at depth is the similarity of the breccia-like Gabbro-10 intrusion and the basal breccia of the Fedorova intrusion (Schissel et al., 2002; Groshev et al., 2019). The difference between the Gabbro-10 intrusion and the basal breccia at Fedorova is that the latter has a relatively uniform thickness in disseminated sulfide mineralization over hundreds of meters, containing up to 8 ppm PGE (1.2 on average). This is explained by a large time gap of more than 700,000 years (Groshev et al., 2009; Groshev et al., 2021). This temporal gap contributed to the cooling of the early intrusive phase. As a result, the pronounced sulfide migration in the additional magmatic phase, which is evidenced by the Gabbro-10 intrusion, did not occur at Fedorova.

Figure 2. Simplified stratigraphic column across the Gabbro-10 intrusion with variations of magnetic susceptibility (MS) and S, Cu, Ni and Pd concentration (Groshev and Pripachkin, 2018).

3. Future prospects

To prove the co-magmatic nature of the gabbroids of the Gabbro-10 intrusion and vein quartz gabbronorites with sulfides and abundant magnetite, it is planned to conduct a comparative

geochemical study to determine the concentration of lithophile and chalcophile elements in rocks (100 samples), analyze the composition of trace elements in sulfide and magnetite by LA-ICP-MS (20 samples), study the isotope composition of Sm, Nd and S in rocks (30 samples) and perform high-precision U-Pb isotope zircon dating using CA-TIMS (5 samples). From an economic point of view, the most important results will be obtained from drilling one or two holes up to 200 m deep in the area of the sulfide ore stocks with Ni contents up to 1.3 wt. %.

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