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PGE reefs of the West-Pana layered intrusion, Kola Region, Russia: plagioclase composition as an indicator of the economic potential

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Abstract. The paper summarizes the present time available data on plagioclase composition through PGE reef sequences in the West-Pana intrusion, Kola Peninsula, NW Russia. The intrusion hosts two PGE-enriched levels with a strongly different economic potential. A lower level is known as “North Reef” and contains several deposits of low-sulfide Pt-Pd ores discovered in past decades whereas an upper “South Reef” level showing high-grade mineralization in some places does not have ore bodies. Comparing the variations of anorthite content in plagioclase through the North Reef with sharp changes from An_{63} in the underlying unit to An_{86} in the reef sequence with those in the South Reef (An_{75} with no significant changes) it is suggested that the formation of the former directly corresponds with an early-magmatic process while the latter has a distinct late-magmatic genesis. Thus plagioclase can be considered as an indicator of the economic potential of PGE reef within the West-Pana intrusion and probably in other layered intrusions when it is necessary to choose the most promising mineralized level in the stratigraphy.

1. Introduction

The West-Pana intrusion is the sheet-like gabbronorite block of the Fedorova-Pana Paleoproterozoic 2.5 Ga Layered Complex on the Kola Peninsula and contains rich PGE reefs in its northern and southern parts. The exploration results obtained by the companies (Barrick Gold, Ural minerals et al.) and the Kola Science Center RAS proved the economic value of the North Reef [1–3], in which two PGE deposits were discovered in 2008 and 2015 (Figure 1). The economic potential of the South Reef turned up to be much lower, instead of high PGE contents received from this reef in the first samples. Thus, the North and South reefs like their analogs in other layered intrusions (e.g., in Bushveld and Stillwater) can be used as reference objects for a comparative study of the PGE-bearing reef-style zones with the different ore potential over a wide range of genetic parameters, including the plagioclase composition.

The petrogenetic value of plagioclase in layered intrusions is discussed in a number of papers [4–9]. Electron probe microanalysis is the main method of plagioclase composition studies. Systematic microprobe data through the West-Pana layered sequence appeared simultaneously with the first information about its PGEs at the end of the last century [4]. The sharp fluctuations of An content in plagioclase were established ($An_{63–86}$) in the North Reef sequence studied in those years mainly in outcrops. Besides, the subsequent studies of the sequence in drill cores [10] showed that the particularly exact position of the mineralization in the layered unit is marked by the most calcium plagioclase. On the contrary, the composition of plagioclase through the South Reef shows no significant variations [11] and reflects a clear genetic distinction with the North Reef. The aim of this small paper is to demonstrate the different styles in variations of plagioclase composition across the most important ore zones of the West-Pana intrusion and to discuss a possible significance of plagioclase as an additional tool for resource assessment of PGE reef.

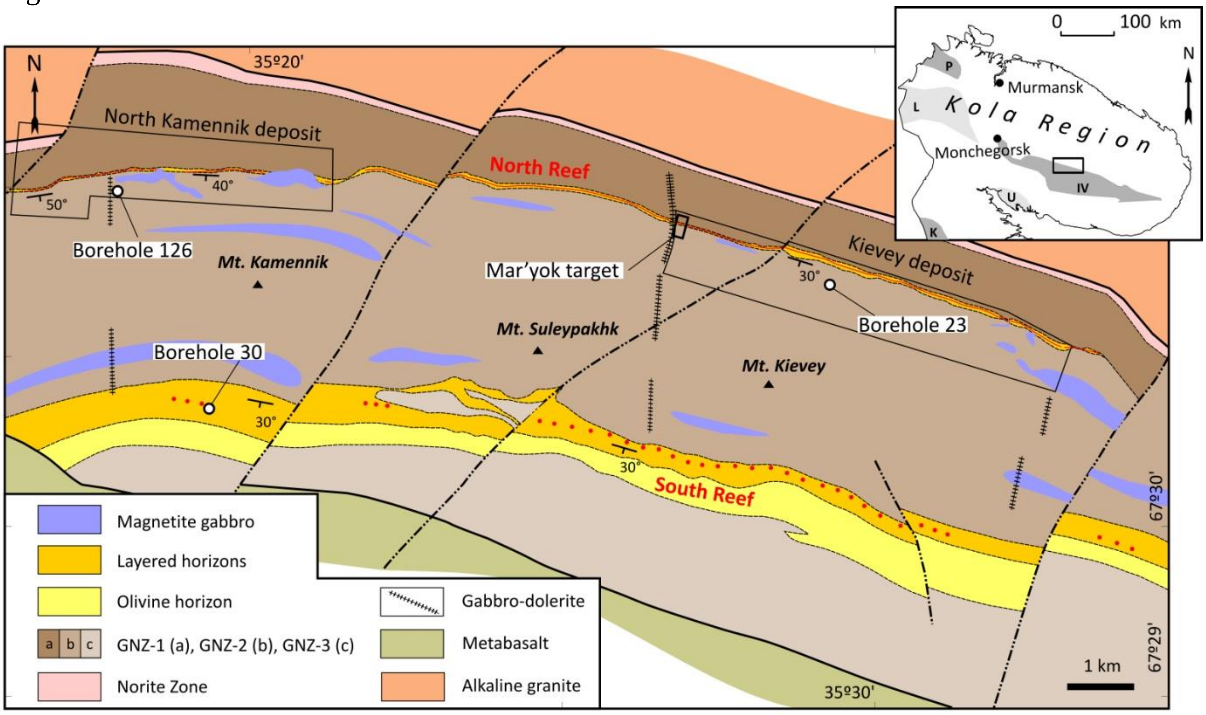

Figure 1. Simplified geological map of the West-Pana intrusion. Note that the intrusion was explored for PGE mainly along strike of the North and South Reefs, but sub-economic to economic deposits were only discovered in the former. Proterozoic structures of the predominantly Archean Kola Region (inset): Imandra-Varzuga (IV), Kuolajarvi (K), and Pechenga (P) paleorift structures; Lapland (L) and Umba (U) granulite belts. Abbreviations: GNZ, Gabbronorite Zone. Modified from [2].

2. Materials and methods

The drill core material from the Kievey (borehole 23), North Kamennik (borehole 126) and South Kamennik (borehole 30) targets was used (Figure 1). Simplified structures of ore-bearing sequences from these boreholes are shown on Figure 2. Detailed description of the boreholes 23, 126, and 30 is presented in [10–12]. Plagioclase composition was studied mainly by electron probe microanalysis (MS-46 Cameca, analyst Y.E. Savchenko, GI KSC RAS, n=80) and EDS analysis (SEM Hitachi SU6600, analyst M. Huber, Maria Curie-Skłodowska University; n>=1000). Composition of plagioclase from the borehole 23 was evaluated indirectly by calculating the CIPW-normative anorthite content in plagioclase for 37 whole-rock analysis (AAS, analyst M.G. Timofeeva, GI KSC RAS). Note that the variations in normative plagioclase composition in the borehole 23 (Figure 3, b) is generally similar to the profile of plagioclase composition at the Mar'yok target (Figure 3, a), composed using 34 microprobe analyses from [4]. The data on PGEs are taken from the internal database of JSC "Pana" with the exception of the Mar'yok target, where ore intervals are shown schematically according to Figure 14 in [4].

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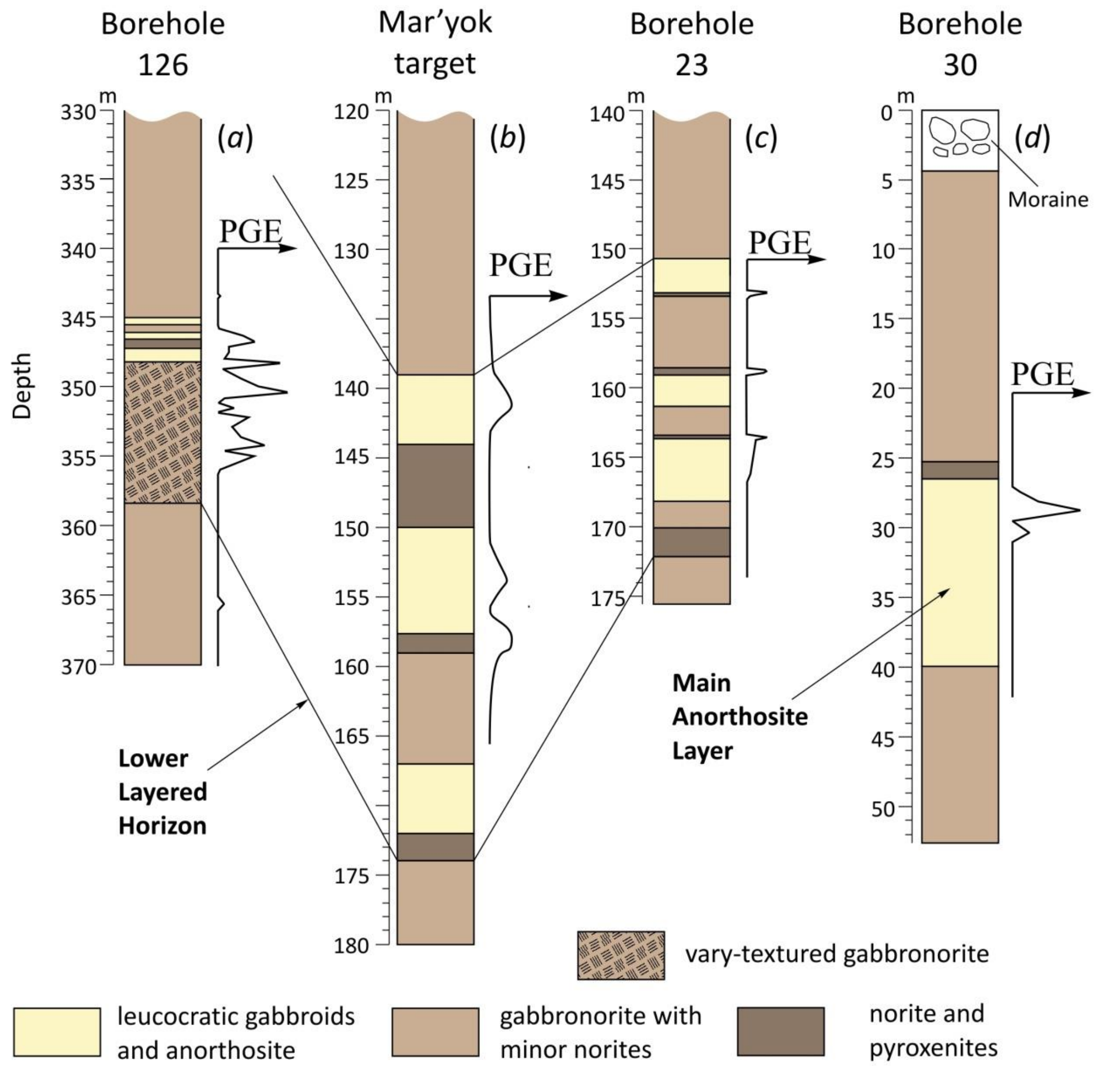

Figure 2. Simplified geologic columns for the North (*a–c*) and South Reefs (*d*) showing the structure of representative ore-bearing sequences of the West-Pana intrusion.

3. Results

3.1. Geological setting

The West-Pana intrusion extends for more than 25 km along strike (Figure 1). The magmatic layering dips southwest at an angle of approx. 30–35° [13]. The stratigraphy of West-Pana is rather simple: the lowermost portion is represented by a thin Norite Zone (50 m) that is underlain by a marginal zone comprised of fine-grained gabbronorite, which is often strongly altered due to tectonic activity along the lower intrusion contact. The remainder of the intrusion is essentially unaltered and consists of massive gabbroic rocks of the Gabbronorite Zone except for two distinct horizons – the lower and upper layered horizons. Mgt G

The Lower Layered Horizon (LLH) is located some 600-800 m above the lower intrusion contact and is composed of several cyclic units, consisting of pyroxenite, gabbronorite, leucogabbro and anorthosite with an average total thickness of 40 m [14]. Significant low-sulfide Pt-Pd mineralization is predominantly concentrated in the second cycle of the LLH (Figure 2, b–c), which is referred to as the "North Reef" [1].

The Upper Layered Horizon (ULH) is situated about 3,000 m above the base of the intrusion and consists of two distinct parts with a total thickness of 300 m [15]. The lower part is a 100-m-thick zone composed of interlayered different rocks (norite, gabbronorite and anorthosite), whereas the upper part is characterized by cyclically interlayered olivine gabbronorite, troctolite and anorthosite. The latter is known as the "Olivine Horizon". The low-sulfide PGE mineralization is associated with both parts of the ULH, but it does not form a continuous ore body. The most significant PGE mineralization is hosted by the "South Reef", which occurs within the Main Anorthosite Layer (Figure 2, d), representing the thickest anorthosite layer in the lower part of the ULH.

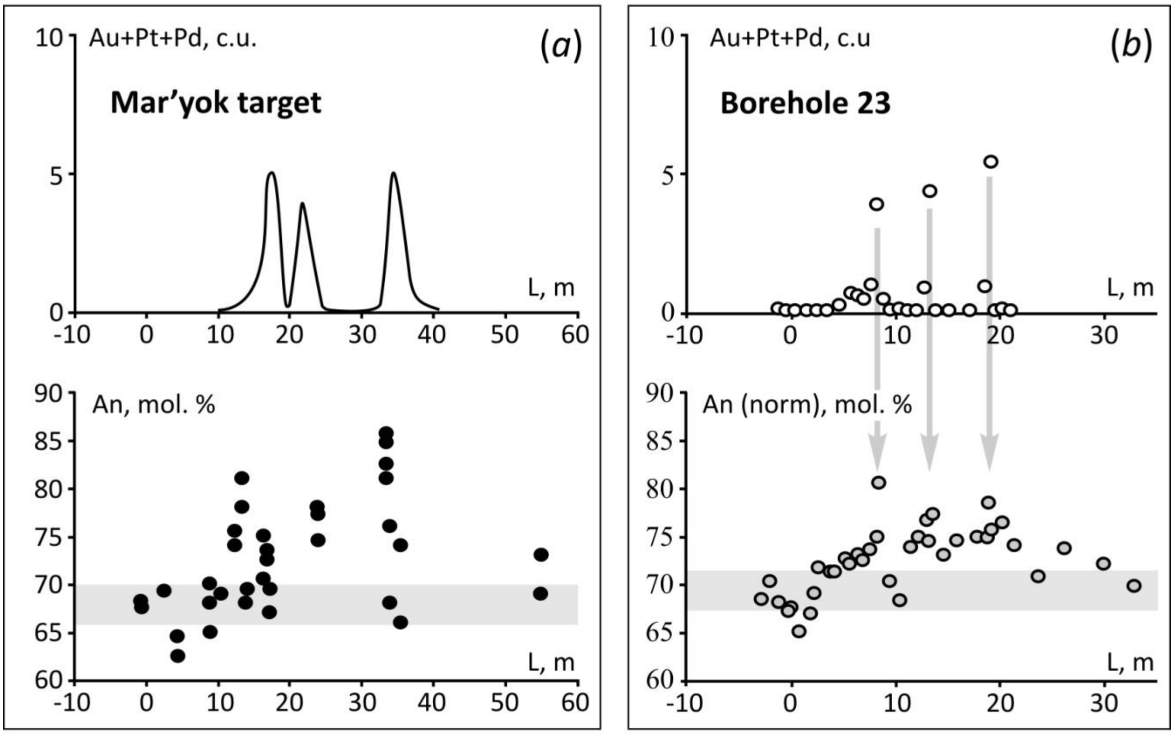

Figure 3. Plagioclase composition and content of Au+Pt+Pd as a function of height from the base of the Lower Layered Horizon (L = 0 m) at the Mar'yok (*a*) and Kievey (*b*) targets. Gray field is an error in determination of An content in plagioclase for microprobe (± 2 mol. %) relative to an average plagioclase composition in the underlying cumulates. Black and gray circles represent microprobe data from [4] and CIPW-norms from [10] respectively. Abbreviations: c.u., conventional units.

3.2. Variations of plagioclase composition across the Lower Layered Horizon

Figures 3–4 shows variations of plagioclase composition and variations of noble metals content in the North reef at its different targets, depending on the height from the base of the Lower Layered Horizon. For better perception, the graph shows a gray field corresponding to the average number of plagioclase in the underlying cumulates, taking into account the analysis error. The ore zone, as can be seen from the figures, appears to be significantly different from the underlying unit by the more basic plagioclase composition – the plagioclase number in the ore zones within all targets of the North reef reaches values of 78–86, while plagioclase in the underlying cumulates corresponds predominantly to labrador. In addition, the detailed study of the Kievey deposit [10] shows that the richest PGE-bearing samples are located on the intervals with the maximum An content in plagioclase (Figure 3, b). Such reversion of the minerals' composition in ore intervals is typical for the well-known economic JM and Merensky reefs [6,16–20] and indicate the genetic relationship of mineralization with the addition of new portions of more primitive magma. The coincidence of the peaks of the noble metals concentrations with maximum contents of An in plagioclase appears to point to a predominant role of an early-magmatic process during formation of the mineralization.

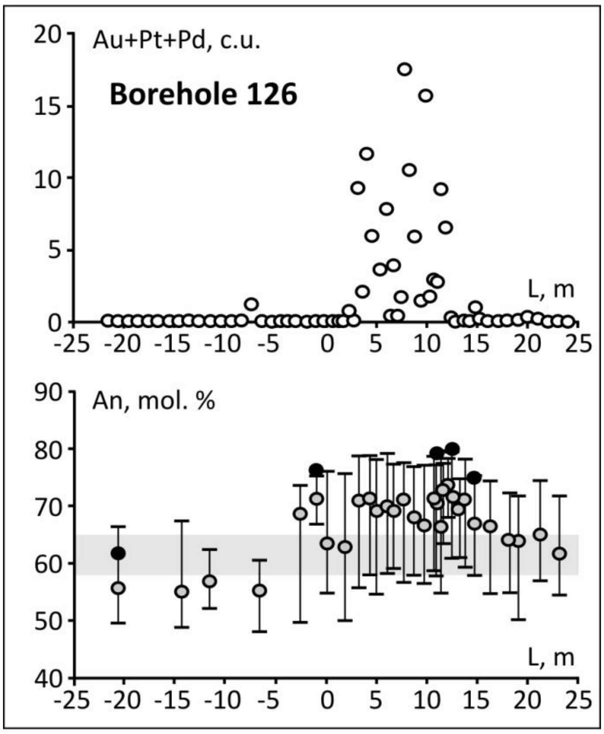

Figure 4. Plagioclase composition and content of Au+Pt+Pd as a function of height from the base of the Lower Layered Horizon (L = 0 m) at the North Kamennik target. Gray field is an error in determination of An content in plagioclase for microprobe (± 2 mol. %) relative to an average plagioclase composition in the underlying cumulates. Black and gray circles represent unpublished microprobe and averaged SEM-EDS data respectively. Note that the SEM-EDS data contains negative systematic error ~7 mol. % An. Abbreviations: c.u., conventional units.

3.3. Variations of plagioclase composition across the Main Anorthosite Layer

Microprobe data on the composition of plagioclase from the section of the South Reef ore zone are taken from [11]. The plagioclase composition was studied by averaging over several analyses separately the cumulus core and the intercumulus rim. Four or five determinations were performed in the cumulus core of a more calcium composition. Figure 5 shows the average compositions of the cumulus cores of plagioclase with the indication of the minimum and maximum values, depending on the distance from the bottom of the anorthosite layer. The gray field is drawn from the average An content in cumulus plagioclase of the gabbronorites in the underlying unit, taking into account the error of ± 2 mol. % An. It can be seen from the figure that the average composition of cumulus plagioclase in the anorthosites, including ore interval, is not significantly different from the plagioclase of the underlying and overlapping rocks and is located within the error margin of the technique. The composition of the intercumulus rim, averaged over 2–3 determinations, is shown in Figure 5 by squares. The intercumulus rim of plagioclase of the ore anorthosites differs by composition from the cumulus cores by 4–6 mol. % An. At the same time, the plagioclase of the barren anorthosites of the lower part of the layer has the margin that is indistinguishable in composition from the core. Thus, the location of the PGE mineralisation of the South Reef, without being distinguished by variations in the composition of the early cumulus plagioclase, correlates with variations of the composition of its intercumulus rim formed during late-magmatic stage of crystallization.

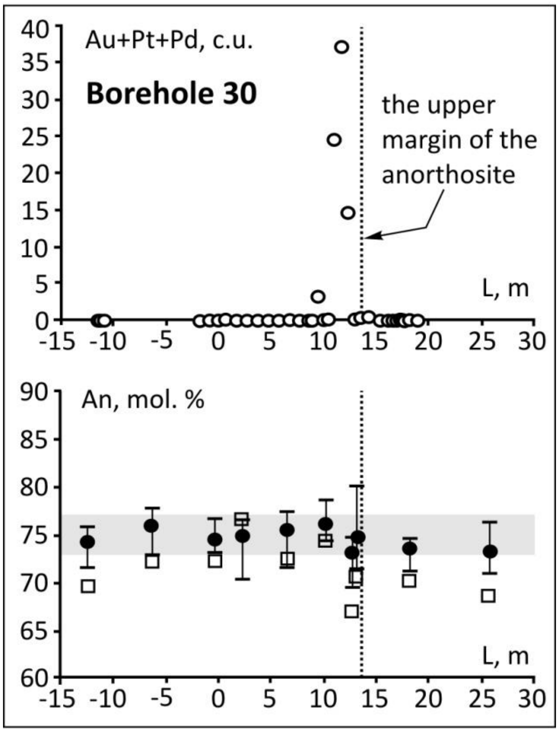

Figure 5. Plagioclase composition and content of Au+Pt+Pd as a function of height from the base of the Main Anorthosite Layer (L = 0 m) at the South Kamennik target. Gray field is an error in determination of An content in plagioclase for microprobe (± 2 mol. %) relative to an average plagioclase composition in the underlying cumulates. Black circles represent averaged [4]composition of plagioclase cores and white squares is averaged composition of the marginal parts of plagioclase grains; microprobe data from [11]. Abbreviations: c.u., conventional units.

4. Discussion

The studied variations of the plagioclase composition across the ore zones of the West-Pana intrusion, where the North Reef has two economic PGE deposits and the South Reef contains only a few ore occurrences, make possible using plagioclase as an indicator of the economic significance of the PGE reef in the central part of the basic layered intrusion and to rank ore intersections at the early stages of exploration. According to the presented data, an intersection of the ore zone should be considered as the most promising, if the PGE mineralization is accompanied by abrupt changes in the composition of the cumulus plagioclase reflecting a link of ore formation with an early-magmatic process. In the case when PGE mineralization is not accompanied by significant variations in the composition of the cumulus plagioclase across the ore-bearing sequence and/or is marked by perceptible changes in the composition of the intercumulus rim, the possibility for the formation of ore bodies is much lower. A possible reason is that the late-magmatic processes are distributed unevenly in the magmatic chamber in general and do not lead to the formation of a uniform mineral body.

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