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GEOCHEMISTRY

Vertical Structure of the Aganozero–Burakovsky Layered Massif and Distribution of Major Elements in Its Section.

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The Middle Proterozoic Aganozero–Burakovsky Massif is the largest layered intrusion in Europe. It contains chromite and Ni-silicate mineralization and is a potential source of platinum [1].

The intrusion (630 km^2) is located in the eastern Onega region (40–50 km to the north of the Pudozh settlement) within Archean metabasites of the Vodlozero block of the Baltic Shield. It is a lopolith with bottom depth varying from 6.5 to 2 km. A thick cover of Quaternary deposits overlay it.

Previous results of investigations [2, 3] were based on the geophysical data and study of scarce outcrops and several shallow boreholes. As a result, the massif outlines, its layered structure, and its thickness were determined.

Deep drilling and geological mapping carried out by the Karelian Geological Expedition over the last 10 years created new possibilities for study of the massif. This paper is a first attempt to reconstruct the complete intrusion section and quantitatively describe the major element distribution from its bottom to the top. Our petrological pattern is based on the data on 80 boreholes with depths of 100–400 m (rarely > 400 m). With depth, each borehole shows a trend of increase in the iron mole fraction $f = \mathrm{Fe}/(\mathrm{Fe} + \mathrm{Mg})$ in the rocks and a trend of decrease in normative plagioclase number An $= (\mathrm{Al} - \mathrm{Na} - \mathrm{K})/(\mathrm{Al} + \mathrm{Na} + \mathrm{K})$. This allows us to demonstrate the vertical standard section (thickness about 6600 m) using data on the 24 most representative boreholes. The section is based on 539 samples related to vertical coordinates of the section.

Based on petrographic study and distribution patterns of major elements, the standard section was divided into **upper** and **lower contact zones**, and **layered series (Ucz, Lcz, LS)**. From bottom to top, LS is subdivided into five zones, whose rocks have different mineral assemblages of the first structural group (cumulus parageneses). Zone boundaries are defined by the abundant appearance of typomorphic cumulus parageneses. Variations in proportions of cumulus phases result in rock diversity in each zone, while the same taxon may correspond to different cumulates because of the variable porosity of cumulus.

The **ultrabasic zone** (Uz) (3000–3500 m thick) contains chromite–olivine cumulates and is composed of dunites, harzburgites, lherzolites, and werhlites. An increased intercumulus mineral levels (to 40% of the total volume) in the upper 400–600 m resulted in the zone being subdivided into lower and upper subzones. Chromite content usually does not exceed several percent, with the exception of the upper zone, where it increases to 30–80% in separate beds with thickness from 1–2 cm to 1.5 m. Some beds with cumulus clinopyroxene, whose thickness increases upward, occur in the upper 150 m of the Uz.

The **pyroxenite zone** (Pz) (100–200 m thick) contains chromite–olivine–clinopyroxene, ortho-clinopyroxene, and clinopyroxene cumulates and is composed of wehrlites, websterites, orthopyroxenites, melanocratic gabbro–norites, and clinopyroxenites.

The **gabbro-norite zone** (GNz) (1100 m thick) mainly contains ortho-clinopyroxene cumulates and is composed of gabbro–norites, norites, and gabbros. The fine contrast alternation of gabbroids, pyroxenites, and peridotites observed in the lower 450 m was used to subdivide this zone into lower (banded) and upper subzones. The upper subzone shows a more uniform distribution of the rock-forming minerals and consists of alternating gabbro–norites and subordinate norites.

The **gabbro–norite zone with inverted pigeonite** (GNPz) (1150 m thick) contains clinopyroxene–pigeonite–plagioclase cumulate and is composed of gabbro–norites with orthopyroxene presented by pigeonite.

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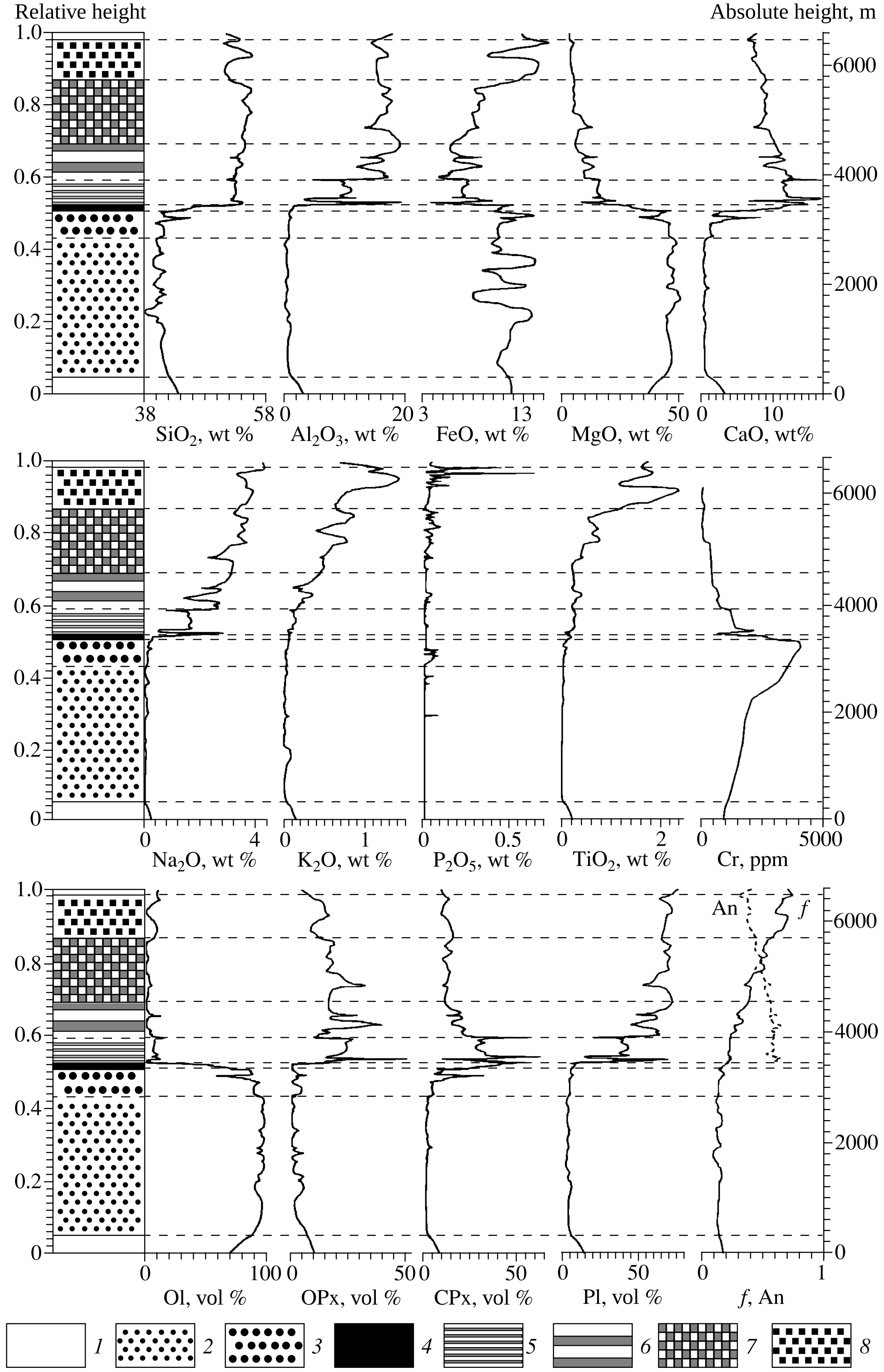

Distribution patterns of major elements and normative minerals in the vertical section of the Aganozero–Burakovsky intrusion. (*1*) UPz, LPz; (*2*, *3*) Uz: (*2*) lower and (*3*) upper subzone; (*4*) Pz; (*5*, *6*) GNz: (*5*) lower (banded) and (*6*) upper subzones; (*7*) PGNz; (*8*) MGNDz.

Indistinct layering caused by alternation of leucocratic and meso-varieties is observed in the zone section.

The **magnetite gabbro–norite–diorite zone** (MGNz) (760 m thick) contains magnetite–pigeonite–clinopyroxene–plagioclase cumulates and is composed of alternating leucocratic and mesocratic gabbro–norite–diorites with gradual transition. The content of cumulus magnetite varies from 30% (at the bottom of the mesocratic layers) to 1–2% (in the leucocratic layers). An content reaches minimum values in the upper part of zone, where it marks the most fractionated rocks of the intrusion and the boundary between the upper part of this zone and the LS.

The presence of LPz and UPz (sampled thickness is 330 and 90 m, respectively) indicates that the complete section of layered series (6100–6700 m in total thickness) is available for investigation.

The cumulus composition are graded upward from high- to low-temperature parageneses: Ol–Chr (Uz), Cpx–Opx–Ol–Chr (Pz), Pl–Cpx–Opx (GNz), Pl–Cpx–Pig (PGNz), Pl–Cpx–Pig–Mt (MGNDz). This sequence is disrupted in two cases: (1) at the boundary between the LPz and LS; and (2) at the boundary between the LS and UPz. Boundaries between the UPz, LPz, and LS was defined by inflection points in the plots of major element distribution.

The distribution patterns of major elements and normative minerals though intrusive section conveniently illustrate the proposed scheme of the massif's structure. To elucidate the main patterns of the element distribution, which is complicated by small and medium-scale layering, initial distribution plots (except for P_2O_5) were processed with tenfold smoothing by a three-point sliding window (figure). When passing from one zone to another (from one to another cumulate paragenesis), chemical composition changes and, as a result, normative content of that mineral, which becomes the cumulus component in the overlaying zone, increases. For example, the appearance of cumulus clinopyroxene is accompanied by an increase in Ca content, while the appearance of cumulus magnetite is accompanied by an increase in Fe and Ti concentrations. The maximum concentration of P_2O_5 at the boundary between the LS and UPz marks the most fractionated rocks, as it is an independent criterion of the reliability of this boundary.

The average weighted composition (in wt %) of the intrusion is as follows:

SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
47.05	0.38	7.76	10.24	0.14	27.46	5.13	1.51	0.29	0.03

(similar to Karelian komatiites [4]). This may be taken for the parental magma composition, if the intrusion either is of the monophase type, or if the probable additional injections did not influence the magmatic evolution inside the chamber.

The umulate sequence shows the order of crystallization of the parental magma: Ol + Chr ⟶ OPx + CPx – Ol – Chr ⟶ OPx + CPx + Pl – Ol ⟶ Pig + CPx + Pl – OPx ⟶ Pig + CPx + Pl + Mt (minus denotes the incongruently melting minerals). This order does not contradict the mechanism of crystallization of komatiitic melts.

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