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Mid-Paleoproterozoic titaniferous Elet'ozersky complex of ultramafic-mafic-alkaline rocks in Northern Karelia (Russia) as transitional chamber of Fe-Ti-alkali basaltic magmatic system

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The Elet'ozero complex in Northern Karelia is one of the largest (about 100 km^2) layered mafic-ultramafic intrusions with alkaline core, as the Gremyakha-Vermes Complex at the Kola Peninsula. These intrusive complexes belong to the Mid-Paleoproterozoic Jatulian-Ludicovian large igneous province in the eastern Fennoscandian Shield, which additionally contains alkali Fe-Ti basalts and tholeiitic basalts with variable Ti-content (Sharkov, Bogina, 2006). However, the tholeiitic basalts are predominant rocks, whereas alkaline volcanics were found only in the Kuetsjarvi Group, Pechenga structure (Kola Peninsusula).

The periphery of the Elet'ozrsky complex is mainly made up of fine-grained marginal gabbros, while prevailing inner portion (Layered Series) is represented by alternation of ferroclinopyroxenite, ferrogabbros (olivine gabbro, gabbro, gabbro-anorthosite, as well as orthoclase gabbro, phlogopite gabbro, etc) and their ore-bearing varieties (Bogachev et al., 1963; Kukharenko et al., 1969; Shchiptsov et al., 2007). All rocks of the layered series are variably enriched in Fe-Ti-oxides (magnetite, titanomagnetite and ilmenite), amounting up to 30-40 vol.% and more in ore varieties, averaging 10 vol.%. The core of the massif (about 10% of the area) consists of alkaline rocks: nepheline syenites and Ne-bearing syenites which cross-cut ferrogabbros. Carbonatite veins and diatreme with xenoliths of the massif's rocks also occur there. During the Svecofennian orogeny (1900-1800 Ma), the complex was unevemy deformed and metamorphosed under the amphibolites-facies conditions.

According to our data (Sharkov et al., 2015), the alkaline and mafic rocks of the complex contain two major types of zircon: oscillatory zoned magmatic zircon and porous zircon (hydrozircon) partly or completely developed after the former. Isotopic-geochronological data show that mafic and alkaline rocks were formed almost simultaneously, at about 2080±30 Ma (zircon U-Pb method, SHRIMP-II data); $\varepsilon_{Nd(2100)}$ = +3.4; the formation of hydrozircon was presumably related to the amphibolite metamorphism of the complex during Svecofennian orogeny.

Thus, the Elet'ozero Complex is the oldest manifestation of the intrusive high-Ti mafic-alkaline magmatism at the Karelian Craton. At the same time, there are no any volcanics of such composition and age in Karelia. On the other hand it was found that the Elet'ozero cumulates are close in REE pattern to the alkali basalts of the Kuetsjarvi Group, but strongly differ from tholeiitic volcanics of the Central Karelia (Fig. 1). However, their spidergrams are different, in particular, the Ti, Eu, and Ba contents in the cumulates are higher than those in lavas, and U, Th, Nb, Eu, Sr, lower.

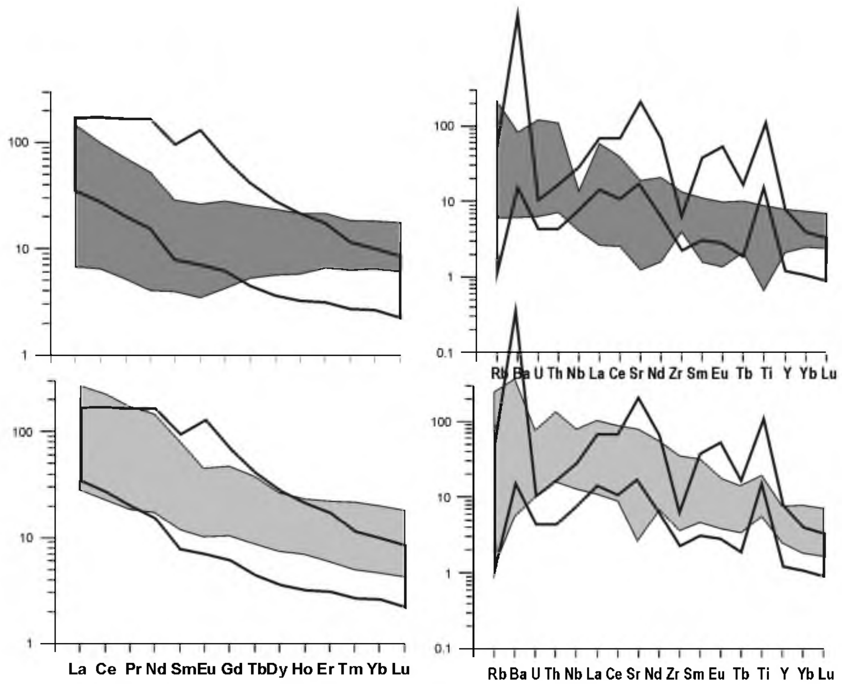

Fig. 1. Trace element patterns for the rocks of Elet'ozero complex (contour) as compared to those of tholeiitic volcanics from the Central Karelia (upper plots) and Fe-Ti alkali basalts of the Kuetsjarvi Group (Pechenga structure, Kola Peninsula, lower plots).

These differences are presumably related to the retention of some components in transitional chamber in cumulates and transportation of others to the surface with lavas. For example, cumulates are often enriched in Ba, Sr, and Eu, as well as Nb and Ta, which led to the depletion of lavas in these components; at the same time cumulates are depleted in U, Th, Nb, and REE, which led to the enrichment of lavas in these elements. So, it is highly probable that the Elet'ozero complex and Fe-Ti alkali were derived from a common source, representing, correspondingly, a transitional magma chamber and volcanic counterpart of a single magmatic system.

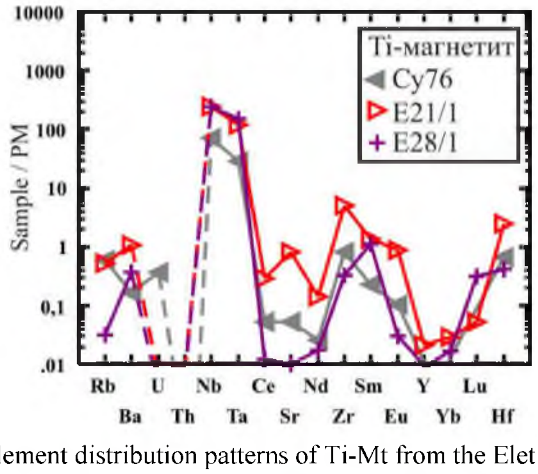

Fig.2. Trace-element distribution patterns of Ti-Mt from the Elet'ozero's ferrogabbros.

The Elet'ozero complex is an important source of Fe-Ti-oxide ores. The analysis of these oxides showed that they are enriched in Nb and Ta (Fig. 2) and may be also considered as Nb-Ta ores. Besides, independent rare-metal and REE mineralization was found in the veins of alkaline pegmatites, associated with Fe-Ti-oxide ores.

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Silicate-carbonate liquid immiscibility in melilitolite from Pian di Celle volcano (Umbria, Italy)

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Melilitolites represent the final event in the activity of the late Pleistocene Pian di Celle tuff ring and lava flow volcano (Stoppa, 1996). They form a 1-m-thick sill and dykelet swarm in the NE flow-front of the Le Selvarelle venanzite lava. The rocks contain phenocrystal melilite (up to 5 cm), olivine, leucite, phlogopite and Ti-magnetite as essential minerals that resemble in moda to fine-grained groundmass of the country venanzites. The fine-grained groundmass consists of Ti-magnetite, fluorapatite, fluorophlogopite, nepheline, kalsilite, clinopyroxene, Zr-cuspidine, götzenite, umbrianite, khibinskite, Co-Ni-rich westerveldite, sulphides (pyrrhotite, bartonite-chlorobartonite, galena), Fe-monticellite - Mg-kirschsteinite, ilmenite, Na-rich pyroxene and amphibole (Zr-bearing aegirine, arfvedsonite), bario-olgite, bafertisite, and brown or green glass (Sharygin et al. 1996; 2013; Stoppa et al. 1997; Sharygin, 2012). Numerous irregular vugs (up to 3 cm) with well-faceted crystals of the above minerals are observed in this rock. The glassy blebs sometimes occur on the surface of crystals in the vugs. The groundmass glass commonly contains Ca-rich carbonate ocelli with high Sr, Ba and REE (Stoppa, Woolley, 1997) or carbonate-fluorite globules. In addition the presence of carbonate globules is fixed in mineral-hosted inclusions (see Figure 1).

Melt inclusions (5-70 µm) have been identified in both phenocrystal and groundmass minerals of the Pian di Celle melilitolite (Sharygin et al., 1996; Stoppa et al., 1997; Sharygin, 1999, 2001). In phenocrysts (melilite, olivine, leucite), the silicate-melt inclusions are mainly localized in the outer zones, whereas, in the groundmass minerals (nepheline, kalsilite, fluorapatite and others), they are situated in the central zones. Their phase composition is green glass + shrinkage fluid bubble ± carbonate globule ± trapped/daughter crystals. Carbonate globule ($CaCO_3$ or $CaCO_3$+CaF_2) was identified in melt inclusions from all melilitolite minerals, but it is clearly fixed in olivine-, melilite- and kalsilite-hosted inclusions (see Figure 1).

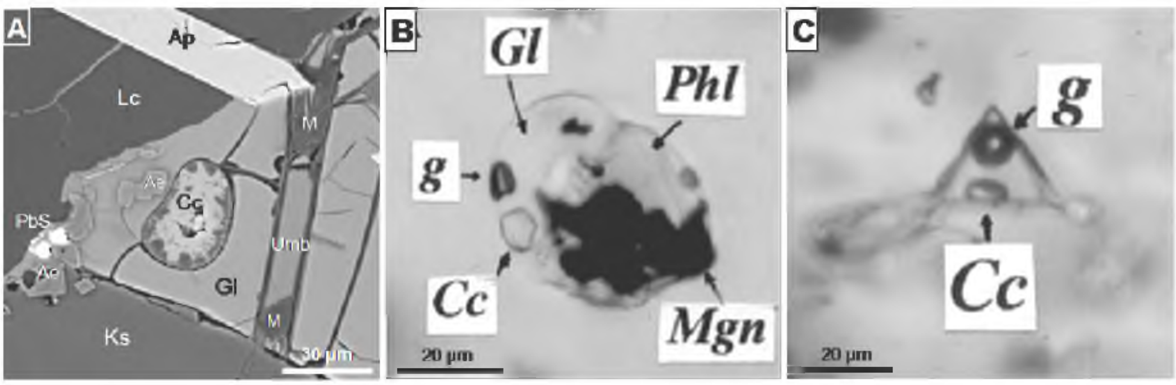

Figure 1. Calcite-fluorite globule in groundmass glass (**A**, BSE image) and silicate-melt inclusions with carbonate globule in the outer zones of melilite (**B**, ordinary light) and olivine (**C**, ordinary light) from the Pian di Celle melilitolite. Symbols: Lc - leucite; Ks – kalsilite; Umb – umbrianite; M – macdonaldite ?; Ap – fluorapatite; Ae – aegirine; Gl – glass; Phl – fluorophlogopite; Mgn - Ti-magnetite; Cc - carbonate or carbonate-CaF_2 globule; g - low-density fluid bubble.