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Middle-proterozoic anorthosite–rapakivi granite complexes: An example of within-plate magmatism in abnormally thick crust: Evidence from the East European Craton

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ABSTRACT

Large, bimodal, and multistage anorthosite–rapakivi granite complexes (ARGCs) of Middle-Proterozoic age (1.8–1.5 Ga) are distinct magmatic assemblages in the western part of the present-day European Craton. ARGCs formation commenced after stabilization of the Svecofennian orogen and relics of its abnormally thick crust occur in many places. In the eastern part of the Kola-Karelian domain and the Volga-Urals domain, where crustal thickness is normal ~40 km, ARGCs are practically absent. Geological data evidence that melting processes occurred both in the crust and in the mantle during formation of the complexes. Geochemical peculiarities of ARGC rocks include enrichment in alkalis (mainly in K), Ti, Zn, Pb, Zr, Be, Sn, In, Y, Nb, Rb, F, Cu, W, Mo, sometimes Li and U. The negative εNd values and relatively high Th and Zn concentrations that are most frequently observed in the rocks imply that parental magmas were considerably contaminated by crustal components.

According to the gravity and seismic profiles, ARGCs represent upper parts of large transcrustal magmatic systems, composed of alternating basic and silicic rocks layers. They are located over mantle uplift structures 10–20 km high, interpreted to represent former mantle plume heads. Origin of transcrustal systems was probably linked with penetrating sill-like bodies of Fe–Ti basalts, which after intruding into sialic crust, caused large-scale re-melting of the granitic material above them, forming two-layer magma chambers. Solidification of such chambers occurred in two stages: lower basic layers solidified first while heated from below, whereas the upper silicic layer crystallized later. Co-existing neighboring chambers led to gravitational instability, overturn, and mass redistribution in large volumes of crust. Furthermore, multistage formation of the ARGCs led to important petrological consequences: contamination of basic magmas by crustally derived SiO_2 and Al_2O_3, causing preferred precipitation of plagioclase and formation of plagioclase cumulates (anorthosites). Diffusion of Na into the basic melt and K into the silicic melt led to the appearance of potassic rapakivi granites.

ARGCs on all Precambrian shields were developed in places with stabilized Paleoproterozoic orogens with atypical unusually thick crust compared with the Phanerozoic, and associated with large Mesoproterozoic belts of within-plate felsic volcanism. Under these conditions, the majority of mantle plume-derived mafic magmas were not able to reach the surface and were lost within the crust in the form of sill-like intrusions with zones of intense melting of a sialic roof. Evidently, ARGCs illustrate structure and processes that are not repeated in the Phanerozoic.

1. Introduction

The middle proterozoic (1.8–1.4 Ga) is characterized by development of wide-spread belts of felsic magmatism all over the World (Condie, 1992; Sharkov and Bogina, 2006). Large unmetamorphosed anorthosite–rapakivi granite complexes (ARGCs) are associated with these belts, and such complexes are known on practically all Precambrian shields (Fennoscandian, Ukrainian, Greenland, Canadian, Aldanian, Amazonian, and Sino-Korean: Rämö and Haapala, 1996). Many investigators suggest that they are a part of anorthosite–mangerite–charnockite granite (AMCG) magma clan, which was also wide-spread among Proterozoic igneous complexes (Emslie and Hegner, 1993; Ahall and Gower, 1997). However, typical AMCG were commonly developed in mobile zones and underwent deformation and high-grade metamorphism (e.g. Priyatkina and Sharkov, 1979; Ashwal, 1993; Corrigan and Hanmer, 1997; Berman et al., 2000; Bogatikov et al., 2000), while anorogenic ARGCs are intraplate, usually localized

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within stabilized cratonic domains, and appeared in places where Paleoproterozoic orogens had completed their development. It is true that some of the major AMCG complexes, such as the 1350 Ma Nain Complex, are still perhaps correctly interpreted as having been emplaced in anorogenic settings, although others, such as the 1650 Ma Mealy Mountain AMCG appear to be correlated with periods of continental arc magmatism (Gower et al., 1990), i.e. had intrabelt settings. So, the geodynamic setting of AMCGs is not uniform, and we suggest distinguishing ARGC as an independent group, whose tectonic setting can be understood in terms of within-plate activity.

The aim of this work is to review current literature and provide evidence touching on the origin of this specific type of the Proterozoic within-plate magmatism using examples of ARG complexes in the Fennoscandian and Ukrainian shields, East European Craton. We also underline their importance for understanding the tectonomagmatic processes in the middle Proterozoic.

2. Geological and geophysical setting

According to current models, the Archean East European Craton was fragmented at about 2.1 Ga with the formation of a pre-Svecofennian ocean on the craton's modern southwestern margin (Korsman et al., 1999). Fragments of Svecofennian oceanic crust are represented as the 1.95 Ga ophiolite complexes at Jormua and Outokumpu (Finland). Based on Sm–Nd dating, closure of the ocean occurred at about 1.90 Ga, and was followed by the Svecofennian orogeny, accompanied by metamorphism and migmatization of volcano-sedimentary rocks under shallow (c. 4.5–5.0 kbar) amphibolite facies conditions (Glebovitsky, 1997). Cratonization of the Svecofennian domain was complete by 1.82 Ga (Korsman et al., 1999).

Continental crust of the Svecofennian domain is abnormally thick reaching up to 60 km in the Central Finnish Granite Massif (Luosto, 1997). Based on geophysical data (mainly gravity and seismic profiles), fragments of the same type of thick crust extends southwards throughout the basement of the East European Platform, reaching the Black Sea (Korsman et al., 1999; Krasnopevtseva and Shchukin, 2000; Yudakhin et al., 2003; Gee and Stephenson, 2006). Importantly, the ARGCs were developed only within the Svecofennian domain and they are usually located in places with thinned crust (Fig. 1). It is assumed that such crust should be considered as Subjotnian (1.65–1.5 Ga) in age, and was modified from the originally thicker crust of Svecofennian age, but details of this process are not yet clear (Korsman et al., 1999). On the Ukrainian Shield, ARGCs intruded metamorphic rocks with U–Pb ages of about 2.0–1.9 Ga (Claesson et al., 2008). Like on Fennoscandian Shield, relics of thick sialic crust existed here and ARGCs are located in places with thinned crust. So, all of the western part of the East European Craton started to look like a unified structure in Svecofennian times.

The Fennoscandian ARGCs were formed from 1.65 to 1.53 Ga. Silicic magmatism of the vast Trans-Scandinavian volcano-plutonic belt (Gorbatschev and Bogdanova, 1993) is somewhat older (1.78–1.59 Ga) and represented mostly by volcanics of dacite-rhyolite composition, some of which are presumably the extrusive equivalents of the ARGC. Practically all ARG intrusions occur within Svecofennian domain; only Salmi massif is located at contact of the Svecofennides and the ancient Karelian Craton (Fig. 2a).

Typical ARG intrusions are large irregular-oval multistage batholiths, ranging from 10 to 100,000 km^2, and geochronological U–Pb data suggest that these plutons were individually emplaced over period of up to 30 Myr (Neymark et al., 2004; Amelin et al., 1994, 1997; Rämö and Haapala, 1996). The ARG intrusions consist mainly of gabbronorite–anorthosite and granite with the latter predominating, i.e. practically bimodal in composition. Texturally, the rapakivi granites, which occur in the Fennoscandian Shield, are characterized by rapakivi textures: presence of ovoidal alkali feldspar megacrysts, mantled by oligoclase-andesine shells (wiborgites: Fig. 3c), or without shells (piterlites). Sometimes occurrence of two generation of alkali feldspar ovoids and smaller idiomorphic grains (Fig. 3a and b) is observed. Locally, rapakivi massifs look like coarse-grained layered intrusions with graduate transition (not rarely with zones of rhythmic interlayering) from gabbronorite–anorthosite via norite, monzonite, quartz-monzonite and diorite to granite (Salmi, Ahvenisto, Korosten, etc., massifs). Basic rocks, mostly gabbronorite–anorthosite, are rare and may be entirely absent. Intermediate rocks play a subordinate role in these plutons, which are essentially bimodal units.

ARGCs formation was accompanied by emplacement of diabase, quartz-porphyry and complex dike swarms. The diabase dikes, intruding the rapakivi granites, are crossed themselves by later units of granite. Injections of basaltic melt into granitic magma chambers sometimes resulted in magma mingling with formation of "fountains" of mafic material among granite material (Haapala and Rämö, 1999).

All plutons have well-defined intrusive contacts with Paleoproterozoic and Archaean metamorphic country rocks. However, these plutons did not undergo regional metamorphism, and unmetamorphosed felsic, potassic volcanics are spatially and genetically associated with them. The volcanic rocks are preserved in gently plunging troughs on the surface of rapakivi plutons, generally overlying them with angular unconformity (Velikoslavinsky et al., 1978). Pb–Nd–Sr isotopic evidence indicates an age range of 1789–1513 Ma for the development of most rapakivi complexes of the Fennoscandian and the Ukrainian shields (Shcherbak et al., 2000; Neymark et al., 2004; Amelin et al., 1994; Rämö and Haapala, 1996; Ahall and Gower, 1997; Levchenkov et al., 1998; Shumlyanskyy et al., 2006; Shumlyanskyy and Bogdanova, 2009).

3. Geology of selected anorthosite–rapakivi granite massifs in the East European Craton

To illustrate the main features of the ARG complexes of the East European Craton we chose three batholiths. They represent all major rock types and geophysical data portraying their interior structures are available.

3.1. Korosten Pluton (1.79 Ma, Ukrainian Shield)

The Korosten pluton is an irregular body, almost rectangular in shape and about 12,000 km^2 in area (Lichak, 1983; Amelin et al., 1994; Shumlyanskyy et al., 2006), intruded into Paleoproterozoic gneisses and migmatites. The intrusive contacts are marked by hornfelsed host rocks, the emplacement of numerous apophyses of rapakivi granite and alkali metasomatism. A sketch map of the intrusion (Fig. 2c) shows that the host rocks locally occur as large xenoliths or erosional windows in the pluton. According to U–Pb zircon and baddeleyite data, the age of the Korosten batholith spans 1.79–1.76 Ga (Amelin et al., 1994). The northern part of the pluton is overlain unconformably by volcano-sedimentary rocks belonging to the 1.761 ± 13 Ma Ovruch Formation, which comprises numerous dacitic and rhyolitic lava flows, and related petrogenetically, geochemically and isotopically to the Korosten batholith (Shumlyanskyy and Bogdanova, 2009). Numerous dykes of titaniferous diabase, quartz-porphyry and granite-porphyry are associated with younger faults.

Mafic rocks, anorthosite and gabbronorite–anorthosite, occur mostly in the southern and central parts of the pluton, forming five "massifs" ("blocks"), that account for about 25% of the