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GEOCHEMISTRY

Charnockites from East Antarctica and Their Geological Typification

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Charnockitic rocks (orthopyroxene-bearing granitoids) are important and characteristic rocks exposed in East Antarctica (Fig. 1). The origin of these rocks and their tectonic setting has been a matter of hot debate since the pioneering studies in Antarctica. The emplacement of intrusive charnockites was interpreted as an indication of cratonization of the Early Precambrian Antarctic Shield or its subsequent tectonic activity [1]. The charnockitic rocks were regarded as intracontinental and anorogenic formations [2]. According to [3], charnockites are orogenic rocks. In this communication, we present new geological and geochemical data on intrusive charnockites from the central Dronning Maud Land (DML) and compare them with the previously investigated charnockites from the Mac.Robertson Land (MRL) [4] and Bunger Hills [5]. The observed differences are related not only to variations of petrogenetic factors but also to tectonic conditions of generation and emplacement of plutons in areas characterized by different scenarios of geological history and geodynamic setting. We suggest the existence of different geochemical types of these rocks related to variations in the composition of provenance and specific features of the tectonic evolution of mobile belts or craton activated areas.

The structure of East Antarctica includes relatively small nuclei of the Archean stabilization and the large Proterozoic mobile belt [6]. The geological history of the DML is characterized by the Mesoproterozoic tectogenesis (1130–1080 Ma, U–Pb SHRIMP method [7]), the development of bimodal volcanic association and within-plate granitic rocks, as well as the recurrent Panafrican reactivation (570–550 Ma [7]) accompanied by ductile deformation and granulite-facies metamorphism. The *PT* conditions were characterized by decompression from 8 to 3–4 kbar [8]. Other segments of the Proterozoic mobile belt differ in the sequence of geologic events. In the MRL, the tectonomagmatic activity was limited by an interval of 1300–950 Ma and charnockites were emplaced closed to the end of this interval. The Mesoproterozoic juvenile rocks formed in this are under convergent geodynamic conditions [9]. Orthogneisses in the Bunger Hills dating back to 1700–1500 Ma [5] experienced granulite-facies metamorphism 1190 Ma ago. The charnockitic rocks were emplaced 1170–1150 Ma ago. Retrograde metamorphism in the MRL and the Bunger Hills was characterized by isobaric cooling [10].

The Insel charnockitic pluton (~40 km^2) located in the central DML is composed of very coarse-grained porphyric rocks (quartz monzonite, monzodiorite, syenite, and granite). The dark-colored minerals are represented by clinopyroxene, olivine, amphibole, biotite, and occasional orthopyroxene. Ilmenite, magnetite, allanite, fluorite, zircon, apatite, titanite, tourmaline, Cr-spinel, and less frequent molybdenite are accessory minerals [1]. The charnockitic rocks make up two intrusive phases. The older phase consists of relatively melanocratic rocks (largely monzodiorite), while the younger phase includes leucocratic rocks (largely syenite). The emplacement of the second phase dates back to 510–505 Ma (U–Pb zircon age [11]). Charnockites are spatially associated with anorthosites, ferrodolerite dikes, and layered sills of gabbroic rocks (orthopyroxenite, websterite, anorthosite, mangerite, and nelsonite).

The dark-colored Fe-rich minerals commonly correspond to olivine $Fo_{2.5–5.0}$, orthopyroxene $Ca_{1–7}Mg_{14–17}Fe_{76–85}$, and clinopyroxene $Ca_{38–46}Mg_{7–12}Fe_{46–52}$. Amphibole is represented by ferropargasite hornblende enriched in TiO_2 (1.5–2.0 wt %) and depleted in MgO (Mg# = 8–13). Amphibole occasionally occurs in equilibrium with

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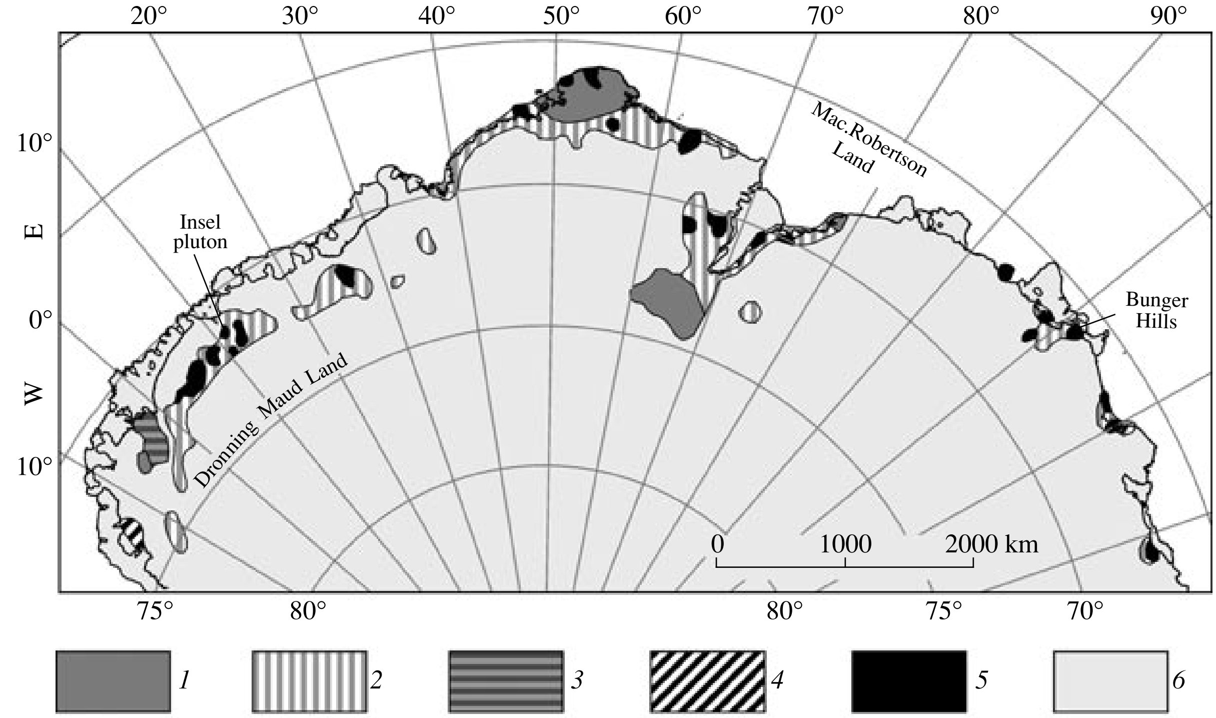

Fig. 1. Simplified tectonic scheme of the Antarctic Shield. (*1*) Archean protocratonic nuclei; (*2*) Proterozoic mobile belt; (*3*) Mesoproterozoic cover; (*4*) Jurassic traps; (*5*) charnockitic plutons of various ages; (*6*) ice sheet and shelf glaciers.

other dark-colored minerals. The late magmatic biotite is also depleted in MgO (Mg# = 5–10) and enriched in TiO_2 (up to 4 wt %) and F (1.62 wt %).

We studied the chemical composition of charnockitic rocks and spatially related rocks of the Insel pluton. In a TAS diagram, they make up a mild-alkaline series (Fig. 2). Charnockites are characterized by more or less linear trends in the majority of binary diagrams for major elements and similar ratios of most microelements (K/Rb = 250–480, Nb/La = 0.47–0.96, Rb/Sr = 0.19–0.35, Rb/Ba = 0.03–0.08, Nb/Y = 0.36–1.16, Ce/Y = 1.8–2.9, and 1000Ga/Al = 2.9–4.0), which testify, at first approximation, to the cogenetic relations of these rocks. The variation of composition may be caused by crystal fractionation and accumulation as confirmed by thin mafic interlayers in charnockitic rocks. Charnockitic rocks from the DML vary from metaluminous to slightly peraluminous (ASI < 1.05) varieties. All the analyzed rocks are characterized by high contents of HFSE (Y 20–120 ppm, Zr 300–2000 ppm, Nb 20–100 ppm, TiO_2 0.3–2.0 wt %, and P_2O_5 0.2–1.8%), lower CaO content (1.5–2.0 wt % at 70 wt % SiO_2) relative to calc-alkaline rocks, and very low Mg# (5–20) (Mg# = 100MgO/(FeO + MgO), mole content). The mafic rocks (layered series and dikes) stand out due to very high contents of Fe (FeO_{tot} up to 30 wt %), P_2O_5 (1.2–2.1 wt %), and TiO_2 (4.0–6.1 wt %) and slightly elevated alkalinity.

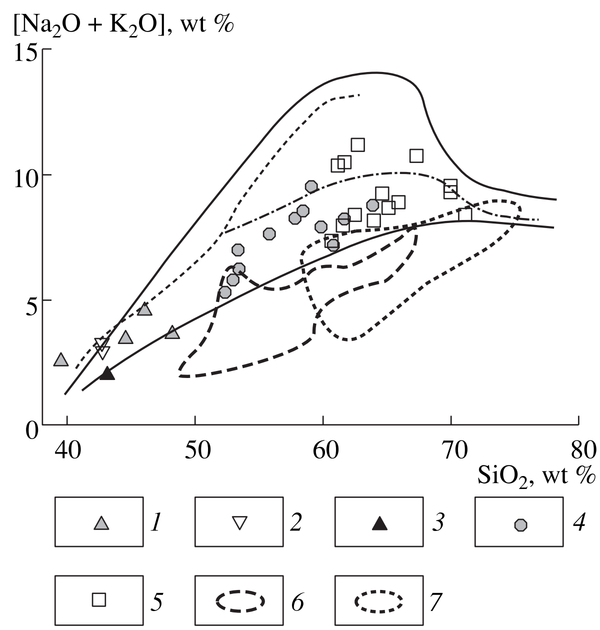

Fig. 2. Compositions of rocks from the Insel pluton plotted on the TAS diagram. (*1*) Gabbro of layered series; (*2*) basic dike; (*3*) mafic interbed in charnockitic rocks of the younger phase; (*4*) charnockitic rocks of the older phase; (*5*) charnockitic rocks of the younger phase; (*6*) charnockitic rocks of the Bunger Hills; (*7*) charnockitic rocks of the Mac.Robertson Land. Boundaries of rock series of various alkalinity are shown after [12].

Table 1. Isotopic composition of Sr and Nd in charnockitic rocks and anorthosites from the Insel pluton

No.	Sample	Rock	[Rb]	[Sr]	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	2σ	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$
1	41049-6	Quartz monzonite	108.2	195.4	1.60357	0.749241	26	0.14221	0.512678
2	41049-2	Quartz monzonite	41.2	34.56	3.45243	0.748271	24	0.12056	0.512442
3	37620-1	Quartz syenite	67.13	42.61	4.61204	0.759412	16	0.13647	0.512318
4	KN18-1	Quartz monzonite	121.1	395.2	0.88710	0.713891	23		
5	KN18-2	Quartz monzonite	122.9	340.9	1.04370	0.715060	15		
6	KN18-3	Quartz syenite	126.6	368.4	0.99490	0.714616	30		
7	KN29-4	Anorthosite	14.97	1475	0.02938	0.706826	26		
8	KN29-2	Anorthosite	25.31	1353	0.05394	0.706941	20		
9	KN48-10	Anorthosite	57.5	1184	0.14060	0.707672	23		

Note: Sample nos. 1–3 were analyzed at the Institute of Precambrian Geology and Geochronology in St. Petersburg (B.V. Belyatsky, analyst); sample nos. 4–9 were analyzed at the GeoForschungs Zentrum in Potsdam (K. Hahne, analyst).

We carried out Rb–Sr and Sm–Nd datings of charnockites and anorthosites (Table 1). Three charnockite samples (nos. 1–3) yielded high $^{87}Sr/^{86}Sr$ values. These rocks are relatively depleted in Sr. The increase in the $^{87}Sr/^{86}Sr$ ratio may be caused by metasomatism of rocks as a result of the reaction with xenoliths of metamorphic basement rocks that are abundant at the sampling site. Samples taken in other areas (nos. 4–9) form the isochron that corresponds to the age of 574 ± 22 Ma (Sr_i = 0.7065; MSWD = 0.134). It should be noted that data points of charnockite and anorthosite samples lie on the same isochron, indicating their cogenetic character or, at least, their relation to the same source.

We scrutinized charnockites from the MRL and the Bunger Hills [4, 5, 13]. Specific features of geological setting and mineral composition of charnockite associations from these localities and from the DML are summarized in Table 2. These associations have much in common with typical charnockitic rocks (elevated contents of K_2O, TiO_2, P_2O_5, and some other lithophile elements; high iron mole fraction; and slightly lower calcium mole fraction). At the some time, the studied rocks reveal substantial differences. Charnockitic rocks from the DML are distinguished by the highest K_2O, Zr, Nb, and Ga contents; high Fe/Mg and Ga/Al ratios; significantly lower MgO content; high ε_{Nd} and low Sr_i values; and elevated iron mole fraction in rock-forming minerals. In many discriminant diagrams, e.g., in (Zr + Nb + Ce + Y)–(FeO*/MgO) coordinates (Fig. 3) [15], the fields of charnockitic rocks from the DML and elsewhere in Antarctica virtually do not overlap. In contrast to other studied areas, the DML charnockites were emplaced into country rocks that underwent decompression shortly before the intrusion. The DML charnockites are associated with high-Fe basic rocks and anorthosites.

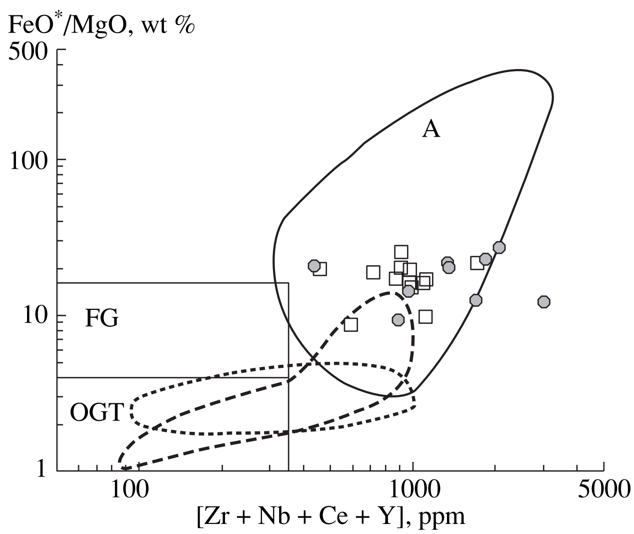

Fig. 3. Charnockitic rocks of the Insel pluton plotted on the (Zr + Nb + Ce + Y)–FeO*/MgO diagram [15]. Fields: (OGT) orogenic granites, (FG) fractionated granites, (A) A-type granites. See Fig. 2 for legend.

All the charnockitic associations of East Antarctica were emplaced at the final stage of tectonic activity, ~20–50 Ma after the main phase of deformation and granulite-facies metamorphism. However, only the DML charnockitic rocks intruded the Early Paleozoic orogen [11], which was a collisional rather than an accretionary process, because juvenile rocks of this stage are absent here and the tectonothermal events are superimposed on the Mesoproterozoic structures [7] that are devoid of mantle derivatives, in contrast to the MRL and Bunger Hills. We suggest that this circumstance was crucial for the specific petrogenetic conditions that controlled the rock composition. The DML charnockites most likely are products of the intense fractionation of mantle-derived high-Fe basic melts. This is indicated by Sm–Nd data with a substantial contribution of the crustal material reflected in the Rb–Sr parameters. The geochemical signature of these charnockites may be accounted for by a substantial influence of an OIB-type within-plate mantle source,

Table 2. Main geological and geochemical properties of charnockitic rocks in East Antarctica

Characteristics	Dronning Maud Land (Insel pluton)	Mac.Robertson Land [4, 8, 9]	Bunger Hills [3, 5, 10]
Zr, ppm	300–2000	120–870	220–650
Nb, ppm	20–104	2–43	4–61
10^4 Ga/Al	2.9–4.7	1.7–2.9	2.0–2.9
Sr_i	0.7074–0.7075; 0.7259–0.7376	0.7063–0.7100; 0.7076–0.7334	0.7091–0.7147
ε_{Nd_i}	from –2.3 to +4.3	from –5.9 to –0.2; from –10.3 to –3.95	–9.4; –3.5
Fe#	0.80–0.95	0.50–0.75	0.50–0.85
Mg# (Hbl)	8–13	49–53	No data
Mg# (Cpx)	13–16	No data	21–45
Mg# (Opx)	10–35	40–45	15–56
Type of associated basic rocks	High-Fe, low-alkaline gabbroic rocks and anorthosites	No	Gabbroic rocks of normal series
Crystallization	510–505 Ma [11]	980 Ma	1170–1150 Ma
Granulite-facies metamorphism of country rocks	570–530 Ma [7]	1000 Ma	1190 Ma
Model of retrograde evolution	Decompression [8]	Isobaric cooling	Isobaric cooling
Deformation of plutons	No	Strong	Strong

Note: Fe# = $FeO_{tot}/(FeO_{tot} + MgO)$, wt % [14].

whereas charnockites from other areas bear IAB-type geochemical features. A more active participation of the OIB component in petrogenesis of the DML charnockites may actually be expected as a result of the evolution of collisional orogen with delamination of the lithosphere and ascent of deep-seated masses that provide the crust with mafic magma, heat, and fluids.

The substantial difference in compositions of charnockites from the DML and MRL–Bunger Hills areas suggests that at least two genetic types of charnockites occur in Antarctica. The first (DML) type may be compared with A-type granites or anorthosite–mangerite–charnockite–rapakivi granite association, which is commonly considered anorogenic formation, while the second (MRL) type is similar to the derivatives of magmatic melt generated in late orogenic environments. At the same time, the DML type was also formed during the final stage of the vigorous tectonothermal process and should not be regarded as an anorogenic formation unrelated to the processes in mobile belts or craton activated areas. Most likely, the collisional nature of orogeny predetermined the origination of the rock association mentioned above.

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