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THE MODEL OF CHARNOCKITE FORMATION PROCESS IN THALA HILLS, EAST ANTARCTICA

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The research was performed in 2008-2009 within Belarus Government target program with the 54-th Russian Antarctic expedition**.** Geological mapping was carried out along with geochemical survey of Precambrian basement of Thala hills in western Enderby Land, Antarctica (lat 67°38,7'S ÷ 67°41'S; long 46°02,7'E ÷ 46°14'E). Peculiarities of geophysical fields correspond to the different petrophysical conditions. In the outcrops within Thala hills, the field relations of plagiogneisses facies, migmatitic and plutonic rocks of charnockite and post-tectonic granitoid affinities are well exposed. Four types of main petrographic and petrophysical heterogeneities were singled out: 1) protolyth - relic two pyroxene amphibole, biotite plagiogneisses (pg); 2) intermediate hybrid amphibole-pyroxene-plagioclase-quartz-feldspathic charnockitic enderbites (čeg); 3) enclosing amphibole-feldspathic-quartz-plagioclase charnockites (čg); 4) in cores – ultrametamorphic feldspathic-quartz-plagioclase-amphibole-biotite streamy rapakivi-gneissic charnockites (hybrids) (čmγ). The rocks correspond to the dominant processes of tectonic thermal activation of the four geochronological borders. The rocks architectonics reflects evolutionary succession of events, i.e. a change of direction of granitization processes from lateral (↔) crustal to vertical (↕) intrusive ones. The territory structure of Thala hills is represented as an ordered linear-dome model of Precambrian structural and compositional evolution: protolyth plagiogneiss ↔, intermediate charnockitic enderbite ↔, enclosing charnockite ↔, core - streamy rapakivioid charnockite ↕.
Key words: geological mapping, East Antarctica, Petrogenesis**,** Petrophysics

Модель процессов формирования чарнокитов холмов Тала, Восточная Антарктида.
О.В. Мясников
Реферат. Исследования выполнены в сезон 2008-2009 гг. в рамках Государственной целевой программы (Беларусь) в составе 54-й Российской Антарктической экспедиции. Выполнены геологическое картирование и геохимические исследования, изучены особенности геофизических полей в разных петрофизических условиях докембрийского фундамента холмов Тала на западе Земли Эндерби, Антарктида (широта 67°38,7' ÷ 67°41' ю., долгота 46°02,7' ÷ 46°14' в.). В обнажениях, расположенных в пределах холмов Тала, хорошо представлены полевые отношения фаций плагиогнейсов, мигматизированных и плутонических пород семейства чарнокитов и посттектонических гранитоидов. Выделены четыре типа основных петрографических и петрофизических неоднородностей: 1) протолит – реликтовые двупироксеновые амфибол-биотитовые плагиогнейсы (pg); 2) переходные гибридные амфибол-пироксен-плагиоклаз-кварц-полевошпатовые чарнокитизированные эндербиты (čeg); 3) вмещающие амфибол-полевошпат-кварц-плагиоклазовые чарнокиты (čg); 4) в ядрах – ультраметаморфические полевошпат-кварц-плагиоклаз-амфибол-биотитовые чарнокиты (гибриды) струйчатые гнейсовато-рапакивиподобные (čmγ). Породы соответствуют доминирующим процессам тектонотермальной активизации четырех геохронологических рубежей. Архитектоника пород отражает эволюционную последовательность событий – смену направления процессов гранитизации от латеральных (↔) коровых к вертикальным (↕) интрузивным. Строение территории холмов Тала представлено как упорядоченная линейно-купольная модель структурно-вещественной эволюции докембрия: протолит плагиогнейс ↔, переходный чарно-эндербит ↔, вмещающий чарнокит ↔, ядро – рапакивиподобный чарнокит ↕.

Модель процесів формування чарнокітів пагорбів Тала, Східна Антарктида.
О.В. Мясников
Реферат. Дослідження виконані в сезон 2008-2009 рр. у рамках Державної цільової програми (Білорусь) у складі 54-ї Російської Антарктичної експедиції. Виконано геологічне картування і геохімічні дослідження, вивчено особливості геофізичних полів у різних петрофізичних умовах докембрійського фундаменту пагорбів Тала на заході Землі Ендербі, Антарктида (широта 67°38,7' ÷ 67°41' півд., довгота 46°02,7' ÷ 46°14' сх.). У відслоненнях, розташованих у межах пагорбів Тала, добре представлені польові відносини фацій плагіогнейсів, мігматизованих і плутонічних порід родини чарнокітів та посттектонічних гранітоїдів. Виділено чотири типи основних петрографічних і петрофізичних неоднорідностей: 1) протоліт – реліктові двопіроксенові амфібол-біотитові плагіогнейси (pg); 2) перехідні гібридні амфібол-піроксен-плагіоклаз-кварц-польовошпатові чарнокітизовані ендербіти (čeg); 3) вміщуючі амфібол-польовошпат-кварц-плагіоклазові чарнокіти (čg); 4) в ядрах – ультраметаморфічні польовошпат-кварц-плагіоклаз-амфібол-біотитові чарнокіти (гібриди) струйчасті гнейсувато-рапаківіподібні (čmγ). Породи відповідають домінуючим процесам тектонотермальної активізації чотирьох геохронологічних рубежів. Архітектоніка порід віддзеркалює еволюційну послідовність подій – зміну напрямку процесів гранітизації від латеральних (↔) корових до вертикальних (↕) інтрузивних. Будова території пагорбів Тала представлена як упорядкована лінійно-купольна модель структурно-речовинної еволюції докембрію: протоліт плагіогнейс ↔, перехідний чарно-ендербіт ↔, вміщуючий чарнокіт ↔, ядро – рапаківіподібний чарнокіт ↕.

1. Introduction

The charnockite genesis is not easy to explain due to complexity of their position, composition, structures and textures. On the basis of petrographic study of charnockites in the Baikal region, Ukrainian shield and India, charnockites were stated to represent an auxiliary group of continuous sequential granitic-protholitic complex, and have spotty, zoned an often domic structure (Айнберг, 1955; Pichamuthu, 1961; Перчук, 1997).

Following the materials of complex petrophysic research, we determined peculiarities of petrogenesis character and formation conditions of main petrographic types of granitoids in the Ukrainian shield (Петрофизика ..., 1987).

The model of charnockite formation process in Thala hills, West Enderby, East Antarctics is created on the basis of field observations, and systematic petrographic and petrophysic research of main granitoid variations. The model basis is the amount of mineral energy for the rocks, as the most universal characteristic of juntctions and processes of any complexity.

2. Petrography

2.1. Gneisses

Two pyroxene-amphibole-biotite plagiogneisses (pg) are observed across the whole research territory in the form of linear elongated relics and xenoliths among the rock masses of charnockite series. In the interval Gnezdovoy cape – Bay of Patience – Rubin, plagiogneisses form large geological bodies 150-300 m. thick. Across the territory, single elongated angulated plagiogneiss bodies ranging in thickness from several decimeters to 1-20 m. are sporadically observed (fig. 1). (Fig. 1-3 see the color paste 1.)

Plagiogneiss masses are represented with protogenic weakly metamorphosed, metamorphized and metamorphic rocks. Depending on the extent of metamorphism, gneisses are divided into dense massive robust weakly modified, friable, sandstone-like and pseudo-layered ones.

The rock composition, texture and structure tell us about its formation in granulite phase of the regional metamorphism over an intrusive rock, probably, of dioritic or gabbro-dioritic composition with insignificant metamorphosis in regressive amphibolites phase (tab.1).

The whole plagiogneiss rock mass is mineralized with garnet (pyrope), titanomagnetite and magnetite.

Table 1

Mineral composition of plagiogneisses

Content, %										
Plagioclase	K-feldspar	Quartz	Pyroxene		Amphibole	Metallic ilmenite, magnetite	Garnet	Apatite	Biotite	Other
			Orthopyroxene	Clinopyroxene						
37-60	0-2	1-6	10-12	6-7	0-29	1-4	< 1	< 1	4-16	Epidote, Chlorite, Sulphides, Carbonate, Zircon (?)

2.2. Migmatites

Hybrid amphibole-pyroxene-plagioclase-quartz-feldspathic charnockitic enderbites (čeg) are found in the center and in the east of the territory at contacts with plagiogneisses where they form lens-like bodies from 50 to 200 m in thickness and extension about one kilometer (fig.1). The contacts are not intrusive as a result of subsequent metamorphization (melting) of protolith into hybrid enderbitic charnockites, rocks with charnockitic fine-grained paleosome, enderbitoid gneiss texture and ovoid femic disseminations.

The structure is emphasized by a directive orientation of some grains of feldspar, quartz and very elongated grains of dark-coloured minerals, mostly hornblende, which crystals are not destroyed, but were formed, apparently, on an already gneissed rock, as well as rare biotite and ore minerals (fig.1, fig.2(d)).

The presence of garnet and hypersthenes proves that the rocks were formed in conditions of granulite phases over granodiorites and were metamorphized in amphibolitic phase to biotite-hornblende gneisse (tab.2).

Table 2

Mineral composition of enderbitic charnockites

Content, %										
Plagioclase	K-feldspar	Quartz	Pyroxene		Amphibole	Metallic ilmenite, magnetite	Garnet	Apatite	Biotite	Other
			Orthopyroxene	Clinopyroxene						
17-50	8-43	16-25	0-10	0-7	1-22	3-7	0-3	1-3	1-6	Epidote, Chlorite, Sulphides, Carbonate, Monazite

Amphibole-feldspathic-quarz-plagioclase charnockites (čg) are abundant in the region structure. They are in contact with all the basic petrographic types (fig.1).

The contact with plagiogneisses is discordant: plagiogneisses are enclosed by charnockites or present among charnockites as xenoliths (fig.2 (a), (b), (d)). The transition from enderbitic charnockites to charnockitic gneisses is concordant, the contact is clear, "magmatic", but not intrusive. The formation of charnockites is the outcome of consequent metamorphism of a lower grade.

As a whole, the charnockitic rock mass has monotonous structure.

The rock is characterized with gneiss structure, conveyed in differentiation of leucocratic and melanocratic minerals into indistinct micro-layers of subparallel direction: large grains of feldspar, quartz, amphibole, biotite foliates, ore minerals grains (tab.3). The dark-coloured minerals form contorted interrupted chains contouring large grains of quartz and feldspar, or form subparallel direction.

Table 3

Mineral composition of charnockites

Content, %										
Plagioclase	K-feldspar	Quartz	Pyroxene		Amphibole	Metallic ilmenite, magnetite	Garnet	Apatite	Biotite	Other
			Orthopy-roxene	Clinopy-roxene						
15-50	18-55	13-32	0-5	0-6	2-15	1-5	0-<<1	<<1-3	<1-3	Epidote, Chlorite, Sulphides, Carbonate, Monazite, Skapolit

Feldspathic-quartz-plagioclase-amphibole-biotite streamy rapakivi-gneissic charnockites (hybrids) (čmγ) occupy the highest elevations. They are in contact with charnockites only, transition to which has facial character as a result of degradation of the source of charnockite formation and the beginning of tectonic thermal processes localization (fig. 1).

These differ from charnockites by a specific streamy structure in plan and beaded augen structure in cross-section (fig. 2 (c)). The volume-linear structures are characteristic of “striate” migmatites, metasomatites and drusites, formed in process of motion of heterogenius subhorisontal extential fluid-thermal stream.

The rock is characterized by inequigranular texture, smoothly curved, indistinctly-oriented structure, which is formed by means of arrangement of the rock grains, differentiated by their size: there can be observed micro-layers, composed of several especially large grains (porphyroblasts) of quartz and feldspar (tab. 4).

Table 4

Mineral composition of rapakivi charnokites

Content, %										
Plagioclase	K-feldspar	Quartz	Pyroxene		Amphibole	Metallic ilmenite, magnetite	Garnet	Apatite	Biotite	Other
			Orthopy-roxene	Clinopy-roxene						
11-32	11-50	23-38	0-4	0	<1-5	<1-3	0	<<1-2	<<1-3	Epidote, Chlorite, Carbonate, Zircon, Monazite, Muscovite

The rock can be related to charnockitic gneisses metamorphised in their regressive amphibolitic phase (charnockitoids, “striate” migmatitic granites of normal row), intermediate from less granitized variations to migmatitic granites.

For better understanding of geological structure underground, profile gravity increment was measured (Δg). Gravimetry data allow concluding about the distribution of rock types and fractures. The results of interpreting the Δg chart are shown on the model of the geologic cross section (fig. 1).

3. Petrophysics

From the point of view of pethrophysics any rock is a complex substance which physical parameters are determined mainly by the properties of the facies it consists of. Density, magnetic, electrical and other physical properties of solid facies are determined by the nuclear structure of the chemical elements of the minerals and depend on the geological conditions of the rock formation.

Petrophysical interpretation is based on values of the three physical parameters – the lattice energy (LE), rock dencity (σ) and the natural residual magnetization (J_n) of the basic petrographic rock types.

The energy required for disintegrating ions to the gas state equals to the energy spent for the formation of the lattice (E_{cryst}). The mineral energy values for the rocks have been obtained on the basis of geoenergetic theory of a crystallic ionic lattice (ЭК) by A.E. Fersman (Fersman, 1958). We have used the data by the Institute of Experimental Minerology of Russian Academy of Sciences and the simplest method of energy calculation, by way of summing up energy of the minerals pro rata with their quantitative content in a rock:

$$U_R = \Sigma LE \text{ (kJ/mol)}$$

The modified method of rock energy evaluation has non-strict simplified character and is convenient for large-scale calculations and acceptable to compositions of any complexity.

The rock density depends on the mineral composition of grains and the binding cement, as well as formation conditions.

The rocks natural residual magnetization (Jn) is conditioned by the content of scattered (accessory) ferromagnetic minerals.

For petrophysical evaluation the arithmetic mean values of the physical parameters (petrophysical “clarkes”) were determined (fig. 3). The values of petrophysical “clarks” for the territory of Thala hills are: potential mineral energy $U_R = 40000$ kJ/mol, density $\sigma = 2,8$ g/sm^3, residual magnetization $I_n = 88*10^{-3}$ A/m.

Plagiogneisses are characterized by high density, increased mineral energy and poor magnetization (fig. 3). The superposition of petrophysical parameters characterizes them as a single rock type. According to their structural position in section and scarnoidic mineralization, they are relics of unprocessed parent rocks. The age[1] of plagiogneisses, subject to metamorphic “rejuvenation”, is determined within 1680÷2275 Ma (Grew, 1978).

The values of natural residual magnetization and density of the enderbitic charnockites are high, the energy values lowen to a medium level. Inverse, in reference to plagiogneisses, positional relationship of the density curves and residual magnetization and subordinate near-contact position in section of the rock mass characterizes enderbitic charnockites as a new genotype, which has inherited the parent rock properties (fig. 3). The age was not determined. According to the energy curve position, their age is younger than plagiogneisses and close to charnockites.

The mineral energy value of charnockites is medium, magnetization and density approach to the minimal values for the area. The dominant distribution, typical petrographic and stable petrophysic data characterize charnockites as a developed “mature” rock type (fig. 3). The stability of phase synchronism of petrophysical parameters of charnockites and enderbitic charnockites characterize them as a single rock type. The age of charnockites is determined within 927÷1047 Ma.

Rapakivioid facial charnockite facies are differentiated by reduced energy values and some increase of magnetization and density (fig. 3). The inphase change of density and residual magnetization trend signs and energy decrease, the appearance and the structural position of the rock point to substantially-genetic affinity with charnockites, but with features of a new intermediate rock type. The age for rapackivioid charnockites is determined within 514÷703ºMa.

4. Energodynamic interpretation

In geological processes of the planet evolution the law of mass-energy continuity is executed by the change of composition, state and properties of the Earth crust when dissipating and

[1] Here after the data of absolute age of the rocks are provided after E.S. Grew, 1978.

converting of the eradiated depth energy. Each mineral species and mineral assemblage is adequate to a definite form, kind and quantity of the occluded energy. Interpretation of geological, geochronological, petrological and petrophysical parameters of the rock types specified within Thala hills allows to characterize Archean and Proterozoic events.

A fragment of the end of Archean geological history within Thala hills territory is imprinted in the most ancient relic two pyroxene-amphibole-biotite plagiogneisses. A high form of energy, high density, low magnetization, geostatic conditions of strain and deformation indicate to the melted state of the mass in conditions of equal dissipation of the energy flow. The decrease in energy level conditioned the formation of the equal solid high energy, according to indirect indications, lower crustal sphere.

Proterozoic history is reflected in a more consistent way due to the charnokitic series, represented within Thala hills by three rock variations. Hybrid amphibole-pyroxene-plagioclase-quartz-feldspathic charnockitic enderbites, rocks with charnockitic fine-grained paleosome and enderbitoid gneiss texture were probably formed in process of plagiogneiss transformation by an energy of a lower form.

Heterogenious composition of the medium in the form of a pseudoliquid mass with relics of a high energy crust caused redistribution and localization of the energy flow and created deviatoric stresses. Mineral recombination in conditions of a lower energy form, increased density and high magnetization, linear structure of the rock-mass due to the impact of rotational powers are stable petrological indicators of the new rock type. The lower age limit of Proterozoic history is not determined, but according to petrological and petrophysical characteristics of charnockitic enderbites affined to the rocks of the Archean and Proterozoic, their age cannot be Palaeoproterozoic.

In the Mezoproterozoic, the energetic conditions persisted, but due to appearing of charnockitic enderbites the flow localization and impact of the horizontal strains increased. During amphibole-feldspathic-quartz-plagioclase charnockites the classic representatives of the charnockite series were in a pseudo-liquid state. Under the impact of the localized energy flows and due to their low density the charnockites bulged, spread, smothered and covered the relics of hard rocks. It would be logical to suppose their dominant role in formation of the granitoid Earth crust.

In conditions of energy degradation in the Neoproterozoic there take place consolidation of the granitic crust layer, energy concentration, transition from viscous to fragile destruction. Ultrametamorphic feldspathic-quartz-plagioclase-amphibole-biotite strial rapakivi-gneissic charnockites (hybrids) are localized in cores of linear-dome structures. Charnockites, formed in conditions of vertical direction and minimal energy flow dissipation, peculiar to an intrusive process, gradually obtain the appearance of rapakivi – plutonic rocks that mark the border of the Proterozoic and Phanerozoic. The linear-punctuate energy concentration is the initial stage fo transition from lateral type of granite formation to the central.

5. Discussion

Summing up the experience of Petrophysical and physico-chemical research charnockite formation mechanisms and zonal metamorphic complexes of the Pribaikalye (Перчук, 1977), the Ukrainian shield (Наливкина, 1964; Петрофизика …, 1987) and Antarctica, we can state that charnockites are the basis of the granite layer and the charnockites series is the visit card of Proterozoic granitization.

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References cited

1. **Айнберг Л.Ф.** К вопросу генезиса чарнокитов и пород чарнокитовой серии. Изв. АН СССР, сер. Геол., № 4, 1955, стр. 102–120.

2. **Наливкина Э.Б.** Чарнокиты юго-западной части Украинского кристаллического массива и их генезис. Москва, «Недра», 1964. – 117 с.

3. **Петрофизика** гранитоидов Украинского щита / Толстой М.И. и др. – Киев : Наук. думка, 1987. – 240 с.

4. **Перчук Л.Л.** Глубинные флюидные потоки и рождение гранита // Соросовский Образовательный Журнал, 1997. № 6, С. 56–64.

5.**Ферсман А.Е.** Избранные труды. Т. 4. М., Изд-во АН СССР, 1958. – 588 с.

6. **Crystallographic** and Crystallochemical Database for Minerals and their Structural Analogues. Institute of Experimental Mineralogy Russian Academy of Sciences. World Wide Web Address: http://database.iem.ac.ru/mincryst/rus/s_lattice.php.

7. **Grew E.S.** Precambrian basement at Molodezhnaya Station, East Antarctica. Geological Society of America Bulletin, v. 89. 1978, p. 801–813.

8. **Pichamuthu C.S.** Transformation of peninsular gneisses into charnockites in Mysore state, India // J. Geol. Soc. India, 1961, v. 2, p. 46—49.