New evidence for the early Archean evolution of Aker Peaks, Napier Mountains, Enderby Land (East Antarctica)

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Summary Zircons from charnockite-enderbite rocks (Aker Peaks, Napier Mountains), which we have dated by SHRIMP-II, were analyzed earlier by conventional multigrain U-Pb ID-TIMS methods (Belyatsky et al., 1990) but gave equivocal ages. This study shows that the optimal way to evaluate geologic events in such rocks is local ion-probe analysis of complex zircons with preliminary study of CL, BSE, REE patterns. Due to this approach we have obtained, for the first time, reliable ages of magmatic crystallization for studied charnockite-enderbites (3620 ± 30 Ma) and the age of the primary enderbite's protolith (3950 – 3970 Ma). Moreover, in all dated zircons a metamorphic event of 2450 – 2480 Ma is clearly recorded that is in agreement with the granulite-facies metamorphism described by many authors. These conclusions coincide well with our Sm-Nd isotope data for these enderbite-charnockite gneisses.

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Introduction

The oldest rocks of the Earth are the unique source of information not only on the composition of the primary crust but also the environmental conditions on the Earth in early Archean (redox state, the presence and composition of atmosphere and hydrosphere, general temperature regime). One of unique objects is Enderby Land (East Antarctica). For this place the oldest age data (≥ 4 Ga) for crystalline rocks of the Earth have been revealed (Sobotovich et al., 1976). Further studies of Enderby Land different rock units are confirmed the oldest age of this crustal segment (DePaolo et al., 1982; Black et al., 1986; Choi et al., 2006) as well as demonstrated the unique high-grade conditions (≥ 1000ºC) during evolution of these rocks (Sheraton et al., 1987; Sandiford and Wilson, 1984; Harley and Motoyoshi, 2000). This could be due to increased heat flows in early Archean period or to very deep position of this segment within crustal cross-section.

However, applying of modern high-precision/resolution local analytical techniques (like SIMS SHRIMP) for dating the oldest stages of evolution is not simple. As it had been demonstrated in the study of zircon from Mount Sones orthogneisses, Enderby Land (Williams et al., 1984), very local heterogeneity of zircon may be caused by complicated multistage reaction of zircon crystalline structure on ultra-high temperature metamorphism, which took place at least twice during the existence of Napier Complex and re-arranged all isotope-geochronological systems (McCulloch and Black, 1984; Black, 1988). These events caused many reverse-discordant U-Pb age estimations and pseudo-concordant ages which are not reflect the real geologic events. To solve this problem, some pre-analytical study of potentially dated zircons, including geochemical micro-composition of zircons, zircon morphometric analysis and use of statistical methods for outline of valuable ages were proposed by some authors (Harley and Black, 1997; Kelly and Harley, 2005).

Results and discussion

Geological structure of Enderby Land is described in detail elsewhere (Kamenev, 1972, 1975; Black and James, 1983; Sheraton et al., 1987). There can be distinguished early Archean Napier and Proterozoic Rayner rock complexes comprising of tectonically dislocated and repeatedly metamorphosed gneisses of primary magmatic and sedimentary origin. No original geological boundary between these two complexes has been found and primary relationships between the rocks are overprinted by migmatization. At least two stages of high gradient granulitic metamorphism has been distinguished for the gneisses of the Napier complex. The main tectonothermal events affected the complex at ca. 3000, 2900 and 2500 Ma ago, and the magmatic protolith of tonalitic orthogneiss is considered to be of 3800 – 3900 Ma old (Harley and Black, 1997). The main uncertainties are the age of the first granulitic metamorphism which is suggested to take place within the interval 3050 – 2850 Ma as well as the high temperature event around 2500 Ma (Harley and Black, 1997; Kelly and Harley, 2005; Asami et al., 2002; Carson et al., 2002).

Systematization of previously revealed (Belyatsky et al., 1990) U-Pb ages of zircons from metamorphic rocks of Enderby Land and model Sm-Nd ages for the precursors of these rocks (Fig. 1), allowed us to select a region in the south-eastern part of the Napier Mountains characterized by oldest zircon and model Sm-Nd ages (≥ 3500 Ma). This region (Aker Peaks, ~ 66º40'S, 55º20'E) is comprised of metamorphic rocks of layered series of Napier complex, represented here by leucocratic garnet gneisses, quartzite–gneisses with layers and lenses of pyroxene gneisses and crystalline schists with subordinated rocks of massive series (primarily magmatic rocks of tonalite – trondhjemite – granodiorite composition): pyroxene–plagioclase schists, mesoperthite charnockites and enderbites. In the rocks of

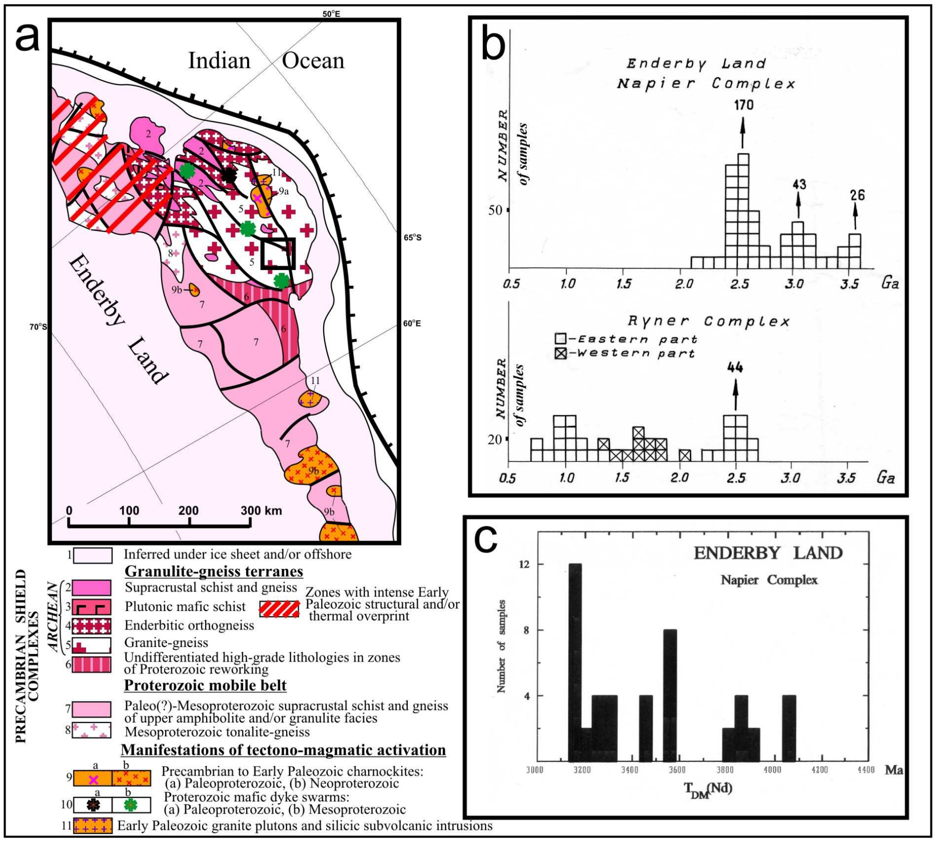

Figure 1. a – Location of the Aker Peaks area (rectangle); b – $^{207}Pb/^{206}Pb$ zircon age distribution within Napier and Rayner Complexes of Enderby Land; arrows and numbers mark main tectonothermal events and quantity of studied samples corresponding to these events; c – Nd isotope model age (against depleted mantle source) distribution within Aker Peaks area.

massive series there are swarms of dolerite dykes, 1 to 20 m in thickness, which cut different gneisses and charnockites. The principal feature of the massive charnockite–enderbite gneiss in this region is absence of any signatures of migmatization processes. Detailed description of geological structure of the Aker Peaks region, metamorphic evolution of the rocks and geochemical characteristics can be found elsewhere (Kamenev, 1969, 1972, 1975; Krylov and Ustinov, 1994).

Samples studied in the present work were selected in the region of Aker Peaks during the 11^{th} SAE (1965 − 1966) and represent mesoperthite charnockites consisting of mesoperthite feldspar (68 – 80 %), ortho-pyroxene (2 – 14 %) and anorthite (5 %), partially replacing by K-feldspar. Secondary minerals are quartz (10 – 15 %), displacing K-feldspar and biotite (2 – 3 %), after orthopyroxene.

For SIMS U-Pb dating we have separated zircons from 8 charnockite samples. These zircons are sub-idiomorphic, originally prismatic, often rounded with “melted” facets, from weakly colored to raspberry pink and brown, with elongation up to 2 − 2.5. Very often zircon grains show heterogeneous (two or three phase) crystal structure (Fig. 2). Cores are irregular or oval in shape, dark, not transparent; outer parts are thin zoned with regular birefringence and a number of dust-like inclusions. Also, there are marked crystal parts represented by zoned, transparent, light colored, with low birefringence phases (Fig. 2). Heterogeneity of zircons is well-developed in CL and BSE images (Fig. 2) and indicates complicated crystallization and recrystallization history of zircons. Practically all studied zircon grains show high-U content (≥ 1000 ppm) which explains dark CL-images and strong cracking of the grains.

On the early stages of the study we have analyzed some of charnockite zircon samples by conventional multigrain U-Pb ID-TIMS method (Belyatsky et al., 1990) with application of preliminary air-abrasion treatment and separation of the zircon substance with maximal density to get the non-disturbed zircon material. However, this approach did not reveal age concordancy and colinearity. As a result, there was a lot of uncertainty in discordia construction and the weak estimation of the zircon crystallization age by the upper discordia intersect of 3536 – 3792 Ma. Nevertheless, this has stimulated the further investigations of zircons from the ancient rocks of Aker Peaks.

Our recent data demonstrate that the optimal way how to obtain the correct age of geological events – is the preliminary investigation of zircons by means of CL, BSE, trace element composition and further collection of cogenetic material groups, which permits traditional data evaluation through discordia diagram (Fig. 2).

Due to such approach we obtained, for the first time, the age of magmatic crystallization for charnockite gneisses from the Napier Mountains (3620 ± 30 Ma granodiorite intrusion) and the time of protolith of these rocks formation of 3950 – 3970 Ma ago. This is supported by typical magmatic characteristics of dated zircons, like prevailing distribution of simple prismatic forms and absence of so-called “granulitic” isometric, polyfacet forms, and high Th/U ratio (≥ 0.5), which are usual for zircons from magmatic rocks. Nevertheless, the possibility of the early granulitic metamorphism at this time could not be totally excluded, in this case magmatic precursor of these charnockites could be intruded at 3950 Ma or, alternatively, almost simultaneously to granulitic metamorphism about 3620 Ma.

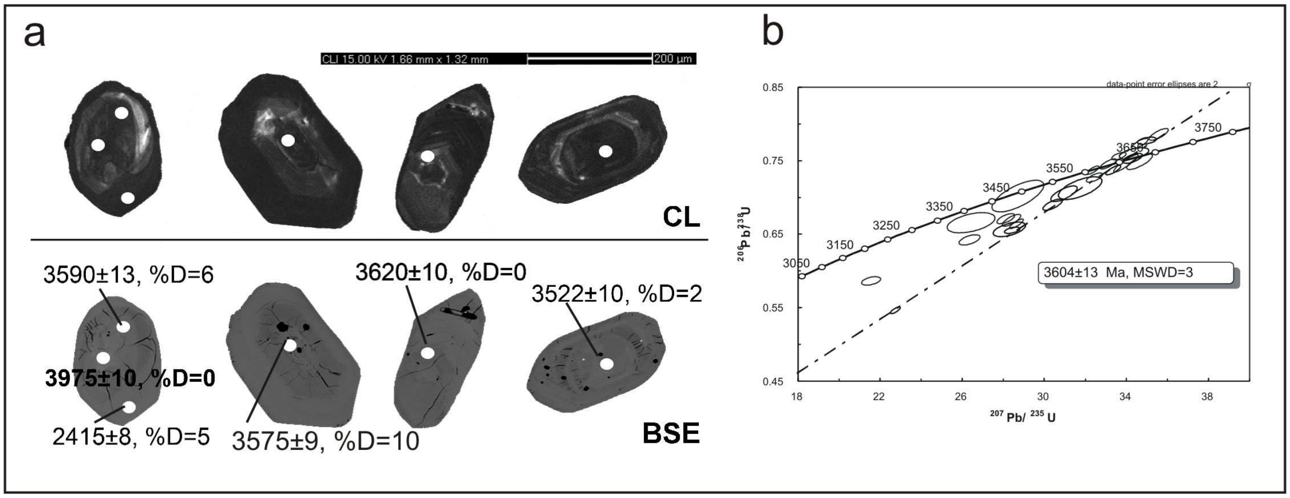

Figure 2. a – CL (top) and BSE (bottom) images of zircons from the studied charnockitic gneisses. Ellipses mark location of analytical spots (SHRIMP), values are: $^{206}Pb/^{238}U$ age (Ma,1 sigma errors) and discordance degree, %D (per cent); b – concordia plot for ancient zircons (SHRIMP-II) from studied samples, the age 3604 ± 13 Ma corresponds to the best-fitted points (n = 8).

Important to note, that we did not found in U-Pb systems of the all studied zircons any records of the other (2850 – 3050 Ma old) high-grade granulite-facies metamorphic events, known for Napier Complex of Enderby Land and which are considered by many researchers (Harley and Black, 1997; Kelly and Harley, 2005) as the main event for the whole Enderby Land. At the same time in all samples there are clear marks of granulite-facies metamorphism of 2450 – 2480 Ma old (Asami et al., 2002; Carson et al., 2002). It is necessary to point out that in spite of the proximity of the studied region to the boundary of the younger Rayner Complex, where the main event is Proterozoic metamorphism 1000 – 1200 Ma (Black et al., 1987), the studied zircons haven't shown its influence upon the host rocks.

These conclusions coincide well with Sm-Nd isotope systematics of the studied charnockite-enderbite gneisses: whole-rock (n = 20) isochron corresponds to the age 3629 ± 110 Ma and ε = +5.6, while mineral isochron, obtained on the sample from which there had been extracted the ancient zircons, shows the age of metamorphic event 2451 ± 86 Ma and ε = -12.2 (Fig. 3). This event is also clearly evident from the mineral isochron data for wide-spread rocks: garnet-bearing plagio-gneiss (2416 ± 14 Ma, ε = -6.9) and migmatitic gneiss (2468 ± 21 Ma, ε = -4.4) (Fig. 3).

The last magmatic event in this region, as mentioned above, was the intrusion of dolerite dykes which gave combined whole-rock + plagioclase isochron corresponding to 2349 ± 61 Ma (ε = -5.7). In general, it supports once more cratonization of the Napier Complex by this time. Initial neodymium isotope composition of the studied charnockites also supports the early Archean origin of depleted (or highly depleted) mantle source and complementary protocrust (Bennett et al., 1993; Choi et al., 2006), at the same time

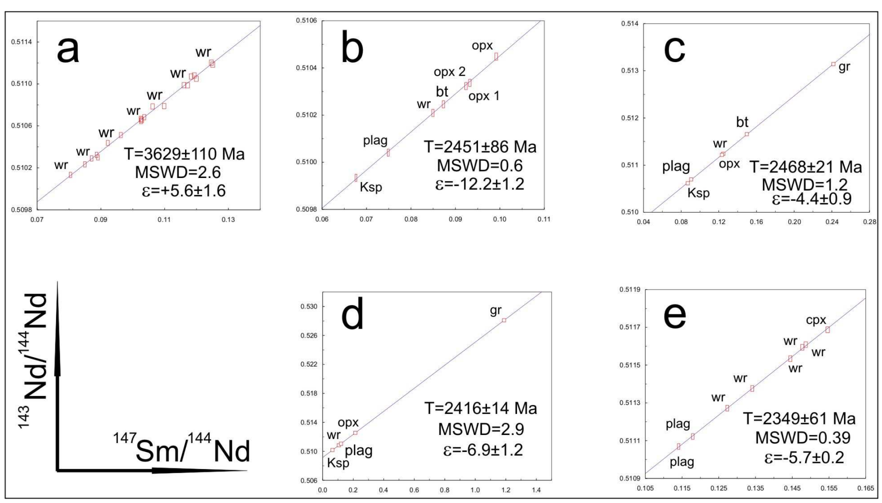

Figure 3. $^{143}Nd/^{144}Nd$ vs. $^{147}Sm/^{144}Nd$ isochron diagrams for Archaean gneisses of Aker Peaks, Napier Mountains: a – whole-rock isochron for massive charnockite gneisses (n = 20); b – internal mineral isochron for charnockitic gneisses; c – mineral isochron for garnet-bearing plagiogneisses; d – mineral isochron for migmatitic gneisses; e – combined whole-rock – plagioclase isochron for dolerite dykes.

mantle source for the dolerite dykes was similar to enriched subcontinental mantle. The variation of ε_{Nd} from -12.2 up to -4.4 for metamorphic rocks within Aker Peaks reflects its different primary composition and origin and in general also evidences to long–lasted pre-metamorphic history of the protoliths of these rocks.

Conclusions

Detailed pre-analytical study of zircons from charnockite gneisses of Aker Peaks by different methods (CL, BSE, REE composition) has allowed estimate the meaningful time of their crystallization by local isotope method SIMS SHRIMP-II and revealing the oldest component, possibly of the primary crust, for this part of the Enderby Land. The age of magmatic crystallization for precursors of the studied charnockites is 3620 ± 30 Ma and the age of their protolith origin is 3950 – 3970 Ma. The main high-grade granulite metamorphic event in this region of the Napier Mountains, which marked by all dated samples at the 2450 – 2480 Ma coincides well with the result of Sm-Nd mineral isochron data for metamorphic minerals of charnockite gneisses. Intrusion of dolerite dykes which cut different gneisses in this region took place at 2350 Ma ago that indicates cratonization of the Napier Complex at about 2400 – 2450 Ma ago.

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